ENDEAVOUR

Volume XIII Number 49

JANUARY 1954

ENDEAVOUR

The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, narrow insularity is avoided by publishing numerous articles from overseas contributors and by impartial reference to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME XIII January 1954 NUMBER 49

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Priests of Pomona

Long Ashton is a Somerset village on the outskirts of the city of Bristol. It is certainly long, and straggling, and has few pretensions to beauty. It has nevertheless achieved fame, for it is known to biologists and horticulturists the world over as the home of the Long Ashton Research Station—locally, with friendly possessiveness, just 'The Cider Institute.' Last year the Station celebrated its jubilee, and in a handsome volume recently published[1] its history and activities are described by several contributors, under the editorship of the director and a senior member of the staff.

The origin of the Station is to be found in the experiments on cider-making started in 1893 and continued until 1903 by a Somerset squire on his home farm near Glastonbury. At that time, cider-making was a crude and haphazard affair, and the product a rough though potent beverage unacceptable to most palates save by long apprenticeship. Squire Grenville was shrewd enough to perceive the possibility of transforming this harsh rustic drink into one of widespread, even national, appeal. He engaged the services of a trained analyst, whose researches on cider and its production were so successful that after some nine or ten years the government became interested. A conference was held to discuss the matter in 1902, and, after the promise of financial help from the Board of Agriculture and other sources, the National Fruit and Cider Institute was established at Long Ashton in 1903.

Though at first the Institute was very modestly housed—the original buildings consisted of a cart-shed and a fowl-house, with lofts above—its sponsors and staff had vision. One of them wrote: 'It is beginning as most things do which really last, in only a small way, but the potentialities are great, and it is hoped that its career may be one of increasing usefulness, not only in this generation but to others which are to follow.' From the outset, an admirably broad view was taken of the purposes which the Institute should serve, research and educational aspects being emphasized as much as the practical ends. Thus the staff were to investigate and demonstrate the best methods of cultivation of all kinds of fruit and vegetables; to promote and carry on research into the factors which affect the manufacture of such fruit products as cider and perry; to improve existing varieties of fruit and vegetables and to create and introduce new varieties; and to disseminate by means of classes, lectures, or any other appropriate methods such results of investigation and research as might be likely to prove useful.

On the sound Suetonian maxim of *festina lente*, the Institute devoted most of its early energies to research on cider-making, but experimental cider-orchards and fruit-plots were established, and desirable and useful contacts were made not only with the local farmers but with the scientific staff at University College (now the University), Bristol. By these activities and by local co-operation—which manifested itself steadily throughout the year and exuberantly on the annual cider-tasting day—the Institute so strengthened its position that in 1912 the government selected it to serve as one of the newly established Agricultural Research Institutes, on condition that it became formally associated with the University of Bristol. As a result of these changes, the director of the Institute became professor of agricultural biology in the University and head of the department of agriculture and horticulture; at the same time the title of the Institute was altered to its present one of the Long Ashton Research Station.

In the period between 1912 and 1953 the Station maintained vigorous progress, and new accommodation had to be added at frequent intervals. Instead of a cart-shed and a fowl-house, there are now several well equipped specialist laboratories, together with a good library, a plant nutrition unit with special equipment for sand-purification and water-distillation, a model cider-factory, greenhouses, workshops, farm buildings, and stores. Moreover, with the multiplication of agricultural stations in various parts of Britain, some of the work with which the Long Ashton Station had burdened itself during the stress of two wars was transferred elsewhere, and the Station is again able to devote itself to the more intensive study of the subjects for which it was originally designed. Its various sections now deal with cider and fruit products, fruit-tree nutrition, pomology, plant-breeding, mycology, entomology, chemistry of insecticides and fungicides, and the culture of willows. A special unit of the Agricultural Research Council, dealing with problems of the mineral nutrition of crops, is also attached to Long Ashton.

[1] 'Science and Fruit: Commemorating the Jubilee of the Long Ashton Research Station,' edited by T. Wallace, C.B.E., F.R.S., and R. W. Marsh, M.A. University of Bristol, 1953. 30s. net.

In a foreword to 'Science and Fruit,' Sir Winston Churchill writes 'More food is needed everywhere in the world, and we in these islands must remain leaders in scientific research into problems of food production. By its past achievements Long Ashton is known wherever these problems are studied.' Those achievements have indeed been weighty and distinguished, and we cannot do more here than briefly refer to a few of them.

First and foremost, because Squire Grenville's foresight was its *fons et origo*, it may be stated that Long Ashton has been the principal agent in converting cider-making from a farm-house and small factory occupation into a large and highly organized industry. This conversion was rendered possible only by careful research into all phases of cider manufacture—from the growing of the apples to the market qualities of the finished product, from the action of bacteria in causing spoilage to the relation between the nitrogen content of apple-juice and the rate of fermentation. In the course of the investigations much new knowledge of theoretical interest has emerged on such subjects as the activities of the organisms involved and the nature of the chemical reactions taking place.

In the field of plant nutrition, one of the most noteworthy of the discoveries made at the Long Ashton Station was that the pathological condition in trees known as 'leaf scorch' is caused by a deficiency of potassium. The application of this knowledge had extremely beneficial effects upon fruit-production, for it enabled thousands of trees regarded as failures to be restored to healthy growth, and large areas of land hitherto considered unsuitable for fruit-growing to be successfully used for this purpose. Methods of visual diagnosis of nutrient deficiencies and excesses were worked out for fruit crops, and later applied to farm and market-garden crops; they were supplemented by other rapid methods, including the use of *Aspergillus niger* for the determination of macro- and micro-nutrients in soils and plant-tissue homogenates and extracts.

The problem of the control of pests and diseases of fruit is one which has engaged the attention of many workers, both in Britain and overseas. Long Ashton has played a worthy part in this field, not only by research upon insecticides and fungicides, but by developing efficient fruit-spraying methods and machinery. As a result of work at this and other stations, it is now possible to control most of the important pests of fruit in Britain, and many of the serious diseases, provided that suitable sprays are selected and adequately applied.

A special section at the Long Ashton Research Station is concerned with the scientific aspects of domestic fruit, meat, and vegetable preservation, such as a determination of the minimum temperatures required to destroy spoilage micro-organisms at the pH values of different fruits, the inactivation by heat of enzyme systems, and the retention of vitamins, particularly ascorbic acid (vitamin C). It was discovered at the Station as long ago as 1915 that apple pomace, a by-product in the manufacture of cider, contains a high proportion of pectin—an important setting-factor in jams—and this is now the main source of supply of pectin in Britain.

Owing to vagaries of climatic and other conditions, it often happens that cross-pollination of fruit-plants is inadequate, with consequent loss of crop. Research has therefore been undertaken by many workers with the object of trying to induce parthenocarpic development of fruit by means of growth-substances. For the tomato, many such substances are known, but experiments carried out at Long Ashton from 1942 to 1944 showed that the most useful for practical purposes is 2-naphthoxy-acetic acid. This substance, when sprayed on to the flower trusses at concentrations of 40–60 parts per million of solution, will induce fruit-set without deforming the foliage, and the fruits produced are of good quality. Growers were not slow to take advantage of this discovery, both for early glasshouse tomatoes and for outdoor tomatoes in poor seasons; full crops of fruit can now be ensured even when conditions for natural fruit-set are unfavourable. 2-Naphthoxy-acetic acid may also be used for spraying strawberries when pollination is defective; a single spray of 20 parts per million has been known to increase the crop by as much as 940 lb per acre. Recently there has been detected in the seeds of young apples a naturally occurring growth-substance which appears to be concerned with the June fruit-drop.

This sketch of the history and some of the achievements of the Long Ashton Research Station will show why we add our congratulations to the very many others received by the Station on the completion of its first half-century. We wish it a long and prosperous future; it will be spurred on by its successes, which will surely be many, but not unduly depressed by its failures. 'The breeding of raspberries at Long Ashton,' says 'Science and Fruit,' 'has not led to any results of practical value'; such engaging candour can well be afforded by a station with so fine a record as that of Somerset's 'Cider Institute.'

Radiocarbon dating

W. F. LIBBY

In this article, the basic principles of the radiocarbon dating technique are presented and discussed. In addition, evidence bearing on the validity of the absolute dates obtained is discussed. The technique of measurement is described and the types of materials acceptable for measurement are given. A partial list of the radiocarbon dates so far obtained is included.

The bombardment of the Earth by cosmic radiation results in the production of neutrons by the disintegration of nuclei of the air atoms. If Geiger counters are sent aloft in balloons one observes [1] that the neutron intensity rises to a maximum at some 50 000 ft and then falls abruptly at higher altitudes, as though the neutrons were not present in the incident primary radiation but were produced by collisions of the primary protons and alpha-particles with the air. This supposition is reasonable since the neutron is known to be unstable, decaying with a half-life of about 13 minutes [2] to form a proton, and could hardly live long enough to traverse the great distances of interstellar space, though it could just reach the Earth from the Sun. Careful measurements made with the balloon technique have revealed an average production rate of 2·4 neutrons/cm^2/sec over the Earth's surface, strong variations with latitude being averaged out [3]. As the neutrons produced by cosmic rays never reach the Earth's surface, some absorptive process must occur in the air, and the question arises of what nuclear species neutrons will produce by reaction with air. In the laboratory, oxygen is observed to be almost completely inert to neutrons, but nitrogen, the principal constituent of air, to have a strong interaction (the nuclear cross-section for thermal-energy neutrons is $1{\cdot}7 \times 10^{-24}$ cm^2). This interaction is almost exclusively due to a single reaction:

$$n + N^{14} = H + C^{14}.$$

Various other possibilities exist. One of these is the production of radioactive hydrogen (tritium) at a small fraction of the radiocarbon yield [4, 5], but the principal product of the cosmic ray bombardment of air, at least that involving neutrons as an intermediary, must be radiocarbon; we can conclude that some 2·4 radiocarbon atoms are produced each second for each square centimetre of the Earth's surface at the present time.

If this rate has obtained in times past, especially during the last several lifetimes of radiocarbon (5568 ± 30 years half-life, or 8030 years average life), we can say with complete certainty that a sufficient store of radiocarbon must exist on the Earth for a steady-state balance to be assured; that is, there must be enough radiocarbon for exactly 2·4 radiocarbon atoms to disappear each second per square centimetre, to ensure that the rate of formation is just equal to the rate of disappearance. Therefore we can calculate with equal certainty that there should be some 80 tons of radiocarbon on the Earth. The rates of radioactive disintegrations are immutable, and under no conditions yet obtained in the laboratory have any appreciable alterations of these rates been observed. We therefore can expect with very considerable confidence that the rate at which radiocarbon reverts to N^{14} by beta-decay is independent of whether it is present in a living organism or in limestone rock or as carbon dioxide in the air.

Where should one expect to find this considerable quantity of radiocarbon, and why has it not long ago been observed? Returning to the mechanism of genesis, we observe that the carbon atoms are formed at an altitude of about 6 or 7 miles on the average. It seems reasonable to suppose that the carbon atoms will burn in the air soon after their birth, to form carbon dioxide, so we conclude that the cosmic rays introduce radioactive carbon dioxide into the air, and that this is probably mixed by the winds so that all the atmospheric carbon dioxide is contaminated at the rate of 2·4 atoms of C^{14} per second for each cm^2 of the Earth's surface. However, it is of course well known that atmospheric carbon dioxide is the main source of plant carbon, through photosynthesis. Therefore we conclude that all plant life must contain radiocarbon. It is obvious also that since animal life lives on plant life it too must contain radiocarbon, and in addition the carbonate and bicarbonate and other inorganic carbonaceous materials dissolved in the sea, which are in interchange equilibrium with atmospheric carbon dioxide,

must contain radiocarbon. The total diluting reservoir apparently contains about 8·3 g of elementary carbon per cm^2 of the Earth's surface. The bulk of it is the dissolved inorganic material in the sea, which amounts to 7·25 g, and the remainder is 0·12 g of atmospheric carbon dioxide and some 0·9 g of living matter all over the Earth, together with dissolved but dead organic matter in the sea-water. Since the bulk of the reservoir is inorganic matter in the sea, which is particularly easy to determine accurately, we are entitled to assume that the total figure, 8·3, is probably accurate to about 10 per cent., even though the estimation of the total amount of living matter on the Earth is a task of great difficulty. If it be correct that there are 8·3 g of carbon involved or being mixed with the atmospheric carbon dioxide on a time-scale of the order of the 8000-year average life of radiocarbon, we can immediately calculate the specific activity of living matter to be 2·4 divided by 8·3 disintegrations per second (16·1 per minute) per gram of carbon contained. The experimentally observed value is 2·12 divided by 8·3 disintegrations per second per gram, or 15·3 per minute.

This satisfactory agreement leads us to believe that the postulate of the constancy of the cosmic radiation in the last 20 000 years or so, and the implied but not specifically stated postulate that the volume of the reservoir has not changed, are probably both correct. It would seem extremely unlikely that the cosmic ray intensity should be causally related to the volume of the sea, for two less cognate physical quantities could hardly be imagined. Therefore we may take it that, since our determination depends on the ratio, the agreement between the calculated and observed specific activity must mean that both the cosmic rays and the volume of the sea have been relatively constant for the last 10 000 or 20 000 years.

Since the cosmic ray neutron intensity varies considerably with latitude [6] one might expect living matter at the equator to be less radioactive than that in the northern and southern regions, the cosmic ray neutron intensity at 50–60° north geomagnetic latitude being some four times that at the equator. On second thought, however, one realizes that this is not likely to be so, for average radiocarbon atoms live 8000 years and therefore have this great length of time to be evenly distributed by winds and ocean currents. Direct tests have shown that this prediction is correct, and that all over the Earth's surface all forms of living matter possess the same radiocarbon activity per gram of contained carbon to within the error of measurement.

Radiocarbon dating is based on the fact that at the time of death the assimilation of radiocarbon ceases. The radiocarbon present in the body at the time of death then proceeds to disappear at its immutable rate. Therefore, we expect that a 5568-year-old mummy or piece of tree or cloth or flesh will show one-half the specific radioactivity observed in living organic matter at the present day. The radiocarbon content of dead matter accordingly reveals the age of the specimen, the age being taken as time elapsed since death rather than, as in normal usage, time elapsed since birth. The error of measurement is determined by the accuracy with which the specific radioactivity can be measured. Direct comparison with organic matter of known age back to 5000 years, the oldest material of known age available, appears to confirm these postulates and deductions. Utilization of the method in the great periods of prehistory has resulted in a series of dates which display some element of consistency and give reason for belief in the validity of the dating technique.

METHODS OF MEASUREMENT

The radiocarbon content of living matter is so low that its measurement is difficult. The procedures used in the author's laboratory consist in the conversion of the sample to pure carbon and the measurement of the radioactivity of the latter. Pure carbon is used, since any diluent atoms will reduce the measurable effect by absorbing the very soft radiocarbon radiation. The measurement of the pure carbon is accomplished by a Geiger counter (figure 2) in which the sample of carbon lines the cylindrical wall. This places the sample in a most advantageous position, where the radiations have a high probability of being recorded. The actual probability attained with a 400 cm^2 area of carbon sample weighing 8 g in all is 5·46 per cent. Since, on the average, we find 15·3 disintegrations per minute per gram of carbon in modern organic matter, we can expect $8 \times 15{\cdot}3 \times 0{\cdot}0546$, or 6·7, counts per minute for modern material in our special Geiger counter.

A counter of the size used normally has a background of five or six hundred counts per minute, this background being due to laboratory contamination by naturally radioactive materials and to cosmic radiation. It is obviously necessary, therefore, that the background be reduced to a very small fraction of its normal value if we are to hope to measure the radiocarbon content of even

modern organic matter. This reduction is accomplished by the apparatus shown in figures 3 and 5. Since the background is due to two different types of radiation, namely, the cosmic rays and the natural radioactivities, we use two types of shielding. For the natural radioactivities a shield of several inches of iron is employed; this will reduce the unshielded background from 600 to 100 counts per minute. This residue of 100 counts per minute is very little reduced by the further addition of iron. As much as 20 ft seems to reduce it by only 20 or 30 per cent. It is clear, therefore, that the cosmic rays cannot be absorbed, and some device for eliminating their effect must be employed. A ring of protecting counters in close contact with one another is placed around the central Geiger counter in which the carbon sample is being measured. They are then wired so that each response in the protecting ring renders the central counter inoperative for a very small fraction of a second. Since the cosmic radiations will penetrate several inches of iron, there is little doubt about their ability to penetrate the fraction of an inch of brass or copper involved in the counter bundle, and any radiation passing through the central counter must necessarily pass through one of the shielding counters, unless it passes directly down the length of the counter. As the figure shows, we have not thought it necessary to place curtains of shielding counters at the ends. With this device the background is reduced to 5 counts per minute. One might worry about the loss of efficiency due to the fact that the central counter is turned off by the action of the protecting counters operating in anti-coincidence. The aggregate count-rate of the shielded counters when located inside the 8-in iron shield is only 900 counts per minute, and since each impulse turns off the central counter for only 1 millisecond at most one is certain that not more than one second is lost out of each minute. It is true in principle, however, that this type of shielding-arrangement has limitations if the size of the assembly is increased greatly. The advantage of putting the shielding counters within the iron shield will also be clear. It is well to note that the radiations from the radiocarbon itself will not be cancelled by the shielding counters, for they are not sufficiently penetrating to pass through the walls of the central Geiger counter. An ordinary sheet of parchment paper stops the radiocarbon radiation practically completely.

With material such as wood or peat, conversion of the samples to elementary carbon is accomplished by combustion to carbon dioxide. With inorganic material such as calcium carbonate, acidification is sufficient to liberate carbon dioxide, which is thus produced for all types of samples. The carbon dioxide needs purification from radon, since small amounts of uranium and radium can be expected in most materials, and both the combustion and the acidification operations will carry the radon along with the carbon dioxide. The purification is accomplished by precipitating calcium carbonate and washing and drying it. The purified calcium carbonate is then acidified with hydrochloric acid and carbon dioxide is produced again. This carbon dioxide is dried and stored in bulbs. Reduction to elementary carbon is accomplished by reaction with pure magnesium metal. Magnesium turnings are placed in an ordinary iron tube about 3 ft long and 1 inch in diameter, connected to the vacuum line. The air is removed, some of the carbon dioxide is introduced, and the tube is heated to the melting-point of metallic magnesium, 651° C. At this point the reduction begins vigorously, and care must be exercised to prevent holes from being burned in the iron tube. With reasonable care the fire can be kept going until the storage bulbs are exhausted. Normally, about 1 gram-atom of carbon is involved, i.e. some 22·4 litres of carbon dioxide.

After the reduction is complete, the solid products are removed from the iron tube and extracted with hydrochloric acid, to remove the excess of metallic magnesium and the magnesium oxide produced in the reaction. This extraction takes 24 to 48 hours and produces a carbon black of about 90 per cent. purity, the remaining materials being magnesium oxide—which for some obscure reason is difficult to remove completely by hydrochloric acid extraction—and about 5 per cent. non-carbonaceous but volatile matter which may be absorbed water, or chemisorbed oxygen, or both. The samples are analysed for carbon, and appropriate correction of the observed count-rates is made.

WORLD-WIDE DISTRIBUTION OF RADIOCARBON

E. C. Anderson [7–9] studied the present distribution of radiocarbon throughout the world. As expected, the strong variation in production-rate with latitude was found to be completely masked by the long lifetime of radiocarbon and the consequent opportunity for world-wide mixing. The data given in table I show no significant variation from the mean for the woods assayed from widely scattered points on the Earth's surface. In examining

TABLE I

Activity of terrestrial biosphere samples

Source	*Geomagnetic latitude*	*Absolute specific activity (disintegrations per minute per gram)*
White spruce, Yukon	60° N	14·84±0·30
Norwegian spruce, Sweden ..	55° N	15·37±0·54
Elm wood, Chicago	53° N	14·72±0·54
Fraxinus excelsior, Switzerland ..	49° N	15·16±0·30
Honeysuckle leaves, Oak Ridge, Tennessee	47° N	14·60±0·30
Pine twigs and needles (12 000 ft), Mount Wheeler, New Mexico ..	44° N	15·82±0·47
North African briar	40° N	14·47±0·44
Oak, Sherafut, Palestine	34° N	15·19±0·40
Unidentified wood, Teheran ..	28° N	15·57±0·34
Fraxinus mandshurica, Japan.. ..	26° N	14·84±0·30
Unidentified wood, Panama ..	20° N	15·94±0·51
Chlorophora excelsa, Liberia	11° N	15·08±0·34
Sterculia excelsa, Copacabana, Bolivia (9000 ft)	1° N	15·47±0·50
Ironwood, Majuro, Marshall Islands	0°	14·53±0·60
Unidentified wood, Ceylon ..	2° S	15·29±0·67
Beech wood (*Nothofagus*), Tierra del Fuego	45° S	15·37±0·49
Eucalyptus, New South Wales, Australia	45° S	16·31±0·43
Seal oil from seal meat from Antarctic	65° S	15·69±0·30
Average		15·3±0·1*

*Error of calibration of counter raises error on absolute assay to 0·5.

this table it is well to remember that, as previously mentioned, the cosmic ray intensity and, therefore, the radiocarbon production-rate are about one-fourth as great at the equator as at the latitude of 50 or 60° geomagnetic north—and, presumably, south also. The further point should be recalled that, the average life of radiocarbon being 8000 years, the radiocarbon atoms now present in living organic matter and in the dissolved carbonaceous material in the sea have been on the Earth for 8000 years on the average, and have therefore had abundant opportunity to circulate throughout the cycle of life and to be moved about in the ocean currents and in the winds of the atmosphere.

The absolute radiocarbon content thus appears to be in reasonably good agreement with the present rate of production of radiocarbon, if we assume that the ocean is mixed with radiocarbon essentially to its full depth. The amount of carbon involved in living forms on land is negligible relative to the inorganic carbon in the sea. In other words the 2·4 atoms being produced per second per cm^2 on the average at the present time, when divided by the 8·3 g of carbon in the ocean and in the life cycle, agree to within 10 per cent. with the observed radiocarbon content at the present time. This plainly indicates that in the course of some 8000 years uniform mixing of the waters of the sea occurs, even at great depths—a point of much interest to oceanographers. It indicates further that the present cosmic ray intensity is not far different from that which obtained 8000 years ago. This latter point is of course vital to the radiocarbon dating method, in that we must assume that the radiocarbon content of living matter at the present time has been its content at all times, and that a piece of wood measured now has the same radiocarbon content as a comparable piece would have had in Egypt 5000 years ago. As we shall see later, there is further confirmatory evidence of this in the apparent agreement found among the radiocarbon contents of carbonaceous samples of historically known age.

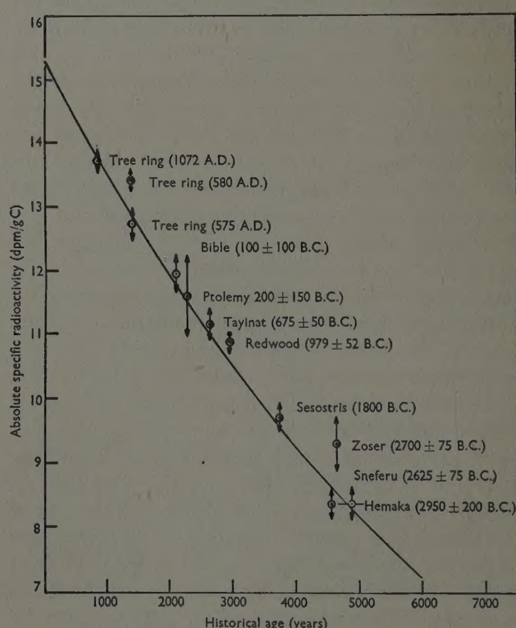

FIGURE 1 – *Samples of known age. The solid curve is calculated from the assay for modern wood and the laboratory measurement of the half-life of radiocarbon. The individual points are the specific radioactivities of various pieces of organic matter, principally wood, of known age. The errors indicated are the standard deviations (which ensure 2 out of 3 chances), and are calculated solely on the basis of the number of counts taken; they do not include any other errors, such as that arising from contamination.*

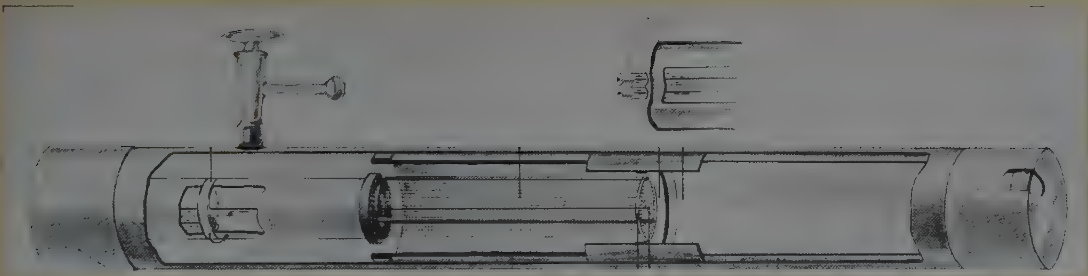

FIGURE 2 – *Screen wall counter. The sample in the form of elementary carbon is disposed round the inside surface of a movable cylinder surrounding a grid, defining the sensitive Geiger counter volume. The two possible positions of the cylinder correspond to the carbon sample being alternately over the grid and removed from it, so the difference in counting-rate is a direct measure of the radiocarbon activity.*

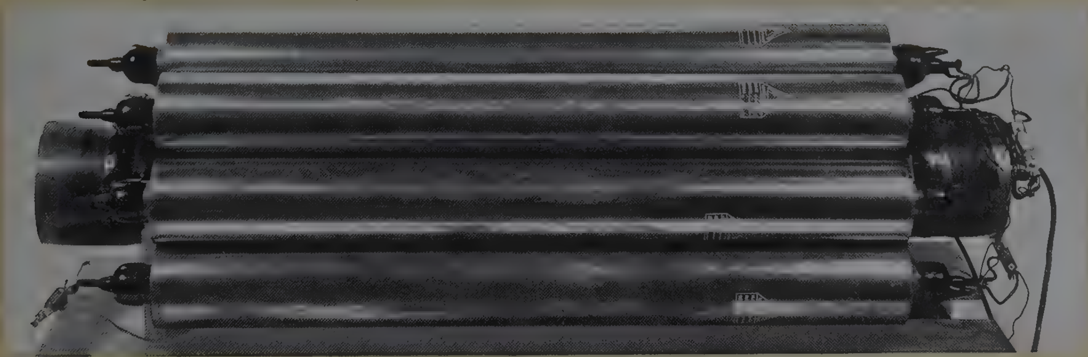

FIGURE 3 – *Side view of the screen-wall counter surrounded by the shielding counters used to cancel out the penetrating cosmic rays. The box contains four counters underneath, making a total of eleven, as shown in figure* 5.

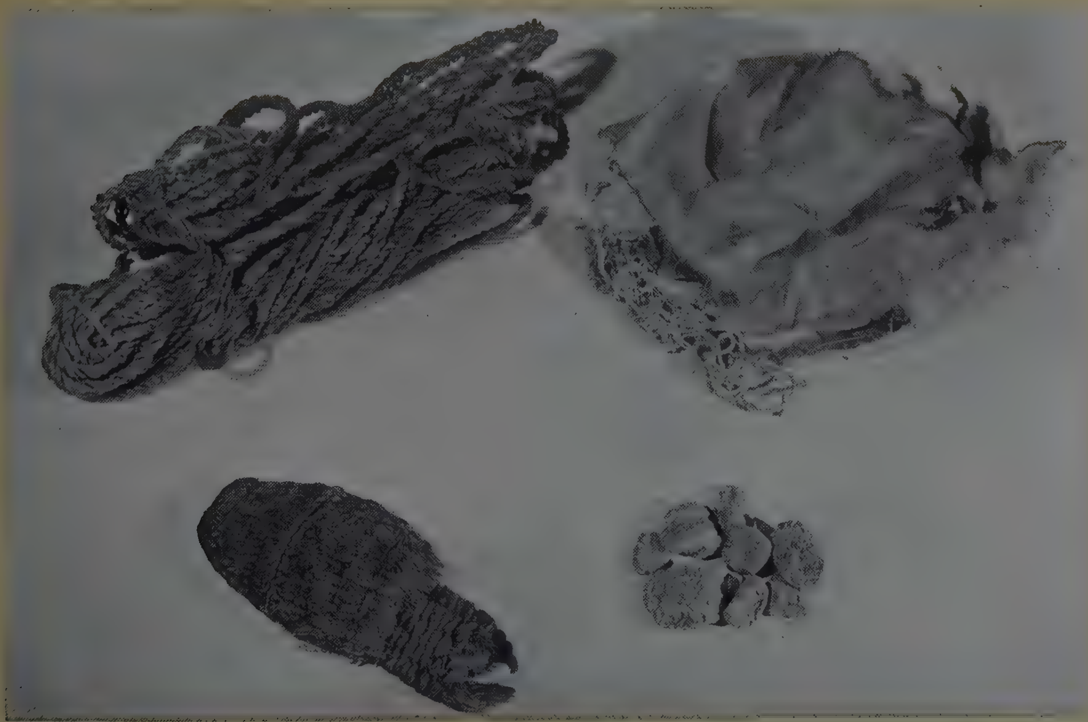

FIGURE 4 – *Typical samples used for measurement. Left foreground, rope sandal from Fort Rock Cave, Oregon,* 9000 *years old. Left rear,* 2000-*year-old rope from Peru. Right rear,* 2000-*year-old cotton cloth from Peru. Right foreground,* 10 000-*year-old faeces of the extinct giant ground sloth* (Northrotherium shastense) *from Gypsum Cave, Nevada.*

FIGURE 5 – *The complete apparatus, consisting of the iron shield (with the door open), the counter bundle in place, and the associated electronic apparatus. The shield has at least* 8 *inches of iron in all directions and weighs some* 6 *tons.*

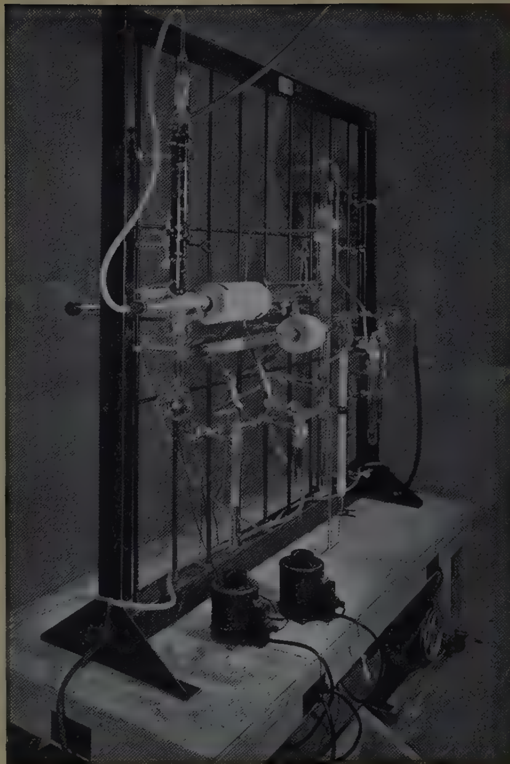

FIGURE 6 – *Typical laboratory vacuum line in which the samples are burned to carbon dioxide, which is stored in bulbs; the carbon dioxide is reduced to carbon by means of metallic magnesium.*

RADIOCARBON DATING

The possible utilization of natural radiocarbon for dating was one of the principal goals throughout the early stages of our research. These consisted in the discovery of natural radiocarbon in Baltimore sewage methane with A. V. Grosse and his collaborators [10], the development of the measurement techniques, and a world-wide assay. We then approached the interesting and crucial stage of testing the dating method with considerable care. J. Arnold joined the group as principal collaborator in this phase of the research. The American Anthropological Association and the Geological Society of America appointed a Committee on Carbon-14, consisting of F. Johnson (chairman), D. Collier, F. Rainey, and R. F. Flint, to advise on the selection of samples for measurement and, most important, to organize a comprehensive test of the method. The Wenner Gren Foundation for Anthropological Research, under its director P. Fejos, gave generous financial support to the research. Part of the development of the low-level counting technique was conducted under contract with the United States Air Force.

The advisory committee decided that it would be possible to test the method against samples of known age back to about 5000 years. This was done, and the results are shown in figure 1. The curve drawn is the exponential decay curve fixed by the laboratory determination of the half-life and the world-wide assay of modern organic matter for radiocarbon (table I). The errors indicated are standard errors as determined solely by the counting-statistics. That is, they are essentially governed by the square root of the total number of counts measured. Experience has indicated that this is the principal source of random error in the measurement, in that repeated measurements on a given sample have shown scatter not inconsistent with this single measure. The materials used as samples of known age are given in table II.

It is clear that with one or two exceptions the

TABLE II

Samples of known age

Sample No.	*Description*	*Age (years) by C^{14} dating*
108A	*Sequoia trunk*, clean borings in growth-rings between year A.D. 1057 and 1087, i.e. known age 880 ± 15 years.	800 ± 600 900 ± 200 1030 ± 200 900 ± 200 Av. 930 ± 100
103	*Broken Flute Cave, New Mexico (Tree Ring)*. Douglas fir wood excavated in 1931 from Red Rock Valley, Room 6, Broken Flute Cave. Inner ring, A.D. 530; outer ring, A.D. 623. Known age thus 1330–1423 years.	973 ± 200 1070 ± 100 Av. 1042 ± 80
108B	*Sequoia trunk* (108A), rings A.D. 570–578, i.e. known age 1377 ± 4 years.	1520 ± 170 1300 ± 200 Av. 1430 ± 150
576	*Bible*. Dead Sea scrolls. Book of Isaiah; linen wrappings used. Found in cave near Ain Fashkha in Palestine. Thought to be first or second century B.C.	1917 ± 200
62	*Ptolemy*. Wood from mummiform coffin of Egyptian Ptolemaic period. Age 2280 years, according to John Wilson.	2190 ± 450
72	*Tayinat*. Wood from the floor of a central room (I-J-1st) in a large hilani ('palace') of the Syro-Hittite period in the city of Tayinat in north-west Syria. Age 2625 ± 50 years, according to R. J. Braidwood.	2696 ± 270 2648 ± 270 2239 ± 270 Av. 2531 ± 150
159	*Sequoia*. Wood from the heart of the giant redwood known as the 'Centennial Stump,' felled in 1874, with 2905 rings between the innermost, and 2802 rings between the outermost, portion of the sample and the outside of the tree. Therefore known age was 2928 ± 51 years.	3045 ± 210 2817 ± 240 2404 ± 210 Av. 2710 ± 130
81	*Sesostris*. Wood from deck of funerary ship from tomb of Sesostris III. Age 3750 years, according to John Wilson.	3845 ± 400 3407 ± 500 3642 ± 310 Av. 3621 ± 180
1	*Zoser*. Acacia wood beam in excellent state of preservation from tomb of Zoser at Sakkara. Age 4650 ± 75 years, according to John Wilson.	3699 ± 770 4234 ± 600 3991 ± 500 Av. 3979 ± 350
12	*Sneferu*. Cypress beam from tomb of Sneferu at Meydum. Age 4575 ± 75 years, according to John Wilson.	4721 ± 500 4186 ± 500 5548 ± 500 4817 ± 240 Av. 4802 ± 210
267	*Hemaka*. Slab of wood from roof beam of tomb of the vizier Hemaka, contemporaneous with King Udimu, Dynasty I, at Sakkara. Accepted age 4700–5100 years, according to Braidwood.	4803 ± 260 4961 ± 240 Av. 4883 ± 200

With the exception of samples 108A and 108B, which were determined by J. L. Kulp and his group at Columbia University [11], the data are to be found in the author's book 'Radiocarbon Dating' [9].

TABLE III

Radiocarbon Dates

Sample No.	*Description*	*Age (years)*
	I. MESOPOTAMIA AND WESTERN ASIA	
	A. EGYPT	
1, 12, 62, 81, 267	*Cf.* Table II.	
463	*Middle Predynastic.* Charcoal from point A-15 of the house floors at El-Omari near Cairo, Egypt. A typological assessment of the position of El-Omari would be about midway between the time of the Upper K pits of the Fayum (Nos 457, 550, and 551) and Hemaka (No 267).	5256 ± 230
C-753	*Shaheinab charcoal.*	5060 ± 450
C-754	*Shaheinab shell.* Bivalve shells from Shaheinab, apparently in fairly unaltered condition. This ancient site may provide a clue to whether some elements in Egyptian civilization came from Africa northward. The site is about 1200 miles from the Egyptian Fayum (samples 457, 550, 551—the Egyptian granaries, which dated 6240 years), and the archaeological connection with the Fayum Neolithic is close.	5446 ± 380
457	*Fayum A (Upper K).* Wheat and barley grain uncarbonized with no preservatives added, from Upper K Pit 13 of the Fayum A material.	6054 ± 330 6136 ± 320 Av. 6095 ± 250
550 and 551	*Fayum A (Upper K).* Wheat and barley grain from Upper K pit 59, Jar 3, and another of the Upper K pits (number lost) of the Fayum A material.	6391 ± 180
	B. IRAQ	
113	*Jarmo.* Land-snail shells fairly well preserved from the basal levels 7 and 8 at Jarmo.	6707 ± 320
C-742	*Jarmo (Jarmo II).* Charcoal. Jarmo is an early village site midway between the towns of Kirkuk and Sulimaniyah. This site is Early Neolithic and exhibits the earliest traces of an established food-producing village economy in the Near East. Only the upper third of the site yielded portable pottery. An excavation labelled I was made clear to virgin soil near one edge of the mound. Eight floors were found. A second excavation, labelled II, was made at the highest point. This went down 4 m through the sixth floor, which is still 3·2 m above virgin soil. The sixth floor of II is equivalent to the third floor of I, and the second floor of II is equivalent to the first floor of I. The earlier Jarmo sample (113), consisting of shell, came from the seventh floor of I.	6606 ± 330
C-743	*Jarmo (Jarmo III).* Charcoal from fifth floor of excavation II (*cf.* samples 742 and 113).	6695 ± 360
	II. WESTERN EUROPE	
	A. FRANCE	
406	*Lascaux.* Charcoal from the Lascaux cave in the Dordogne.	15 516 ± 900

TABLE III (*continued*)

Sample No.	Description	Age (years)
	B. GERMANY	
337	*German Allerød.* Peat with birch remains from Pollen Zone II*b*, the younger Allerød, from Wallensen-im-Hils, north-western Germany,.	11 044 ± 500
	C. DENMARK	
432	*Danish Boreal* (*Danish Boreal II*). Pine cones from Denmark. They are from pollen zone V, thought to be 8500 years old.	7583 ± 380
433	*Danish Boreal* (*Boreal IV*). Hazel-nuts from Denmark. The nuts are from one single summer dwelling, belonging to the late boreal age, pollen zone VI, thought to be about 8000 years old.	9935 ± 440 9927 ± 830 Av. 9931 ± 350
434	*Danish Boreal* (*Danish Boreal III*). Charcoal from the same summer house as No 433. Expected age about 8000 years.	8631 ± 540
435	*Danish Boreal* (*Danish House*). Birchwood from the same area as Nos 433 and 434. From House 2. Probably a few years younger than House 1.	9425 ± 470
	D. IRELAND	
355	*Irish mud.* Lake mud from Knocknacran, County Monaghan. Late Glacial, pollen zone II.	11 310 ± 720
356	*Irish Post-glacial.* Lake mud, Lagore, County Meath. Early Post-glacial, Zone IV.	11 787 ± 700
	E. ENGLAND	
353	*Yorkshire.* Wooden platform from Mesolithic site at Lake Pickering. Pollen zone IV.	10 167 ± 560 8808 ± 490 Av. 9488 ± 350
444	*Neasham.* Lake mud from Neasham, near Darlington. Pollen zone II, correlated directly with last Glacial stage.	10 851 ± 630
341	*Hawks Tor.* Peat from Hawks Tor, Cornwall, late Glacial, pollen zone II, 9 ft to 9 ft 4 in at site 1, middle of lower peat.	9861 ± 500
602	*Stonehenge.* Charcoal sample from Stonehenge, Wiltshire. Late Neolithic.	3798 ± 275
	F. ICELAND	
C-749	*History of the Geomagnetic Field, Reykjavik, Iceland* (*Iceland Peat*). The direction of the Earth's magnetic field is recorded by solidifying lava, at the time of solidification, by the permanent polarization of the lava. Near Reykjavik, a lava flow occurs with polarization roughly parallel to the present geomagnetic field. It happened to flow over Post-glacial peat, which constitutes the sample. Its date correlates directly with that of the flow.	5300 ± 340

TABLE III (*continued*)

Sample No.	Description	Age (years)
	III. UNITED STATES	
	A. LOUISIANA, MISSISSIPPI, NEBRASKA, AND TEXAS	
558	*Folsom Bone.* Burned bison bone from Lubbock, Texas, from the Folsom Horizon.	9883 ± 350
	B. ARIZONA, CALIFORNIA, AND NEW MEXICO	
440 and 522	*California Early Horizon.* Charcoal from near Sacramento, site SJo-68; culture Early Central California Horizon.	4052 ± 160
C-631	*California Crude I.* Crude oil taken from depth of 1100 ft in the Tulare formation, Upper Pliocene age, at the South Belridge field, California.	Older than 24 000
C-632	*California Crude II.* Crude oil from the upper or middle Pico formation, Upper Pliocene age, from the Padre Canyon field, California. This, and sample 631, constitute the youngest crude oil samples measured.	Older than 27 780
	C. NEVADA, OREGON, AND UTAH	
221	*Gypsum Cave.* Dung of giant sloth (figure 4) from Gypsum Cave, Las Vegas, Nevada. Collected in 1931 from room 1, dung layer 6 ft 4 in from surface.	10 902 ± 440 10 075 ± 550 Av. 10 455 ± 340
599	*Leonard Rock guano.* Bat guano taken from immediately next to the Pleistocene gravels in the Leonard Rock Shelter, Nevada.	11 199 ± 570
298	*Leonard Rock Shelter* (*Leonard Rock II*). Atlatl (throwing-stick) foreshafts of *Sarcobatus*, greasewood.	7038 ± 350
247	*Mazama, Oregon.* Charcoal from a tree burned by the glowing pumice thrown out by the explosion of Mount Mazama (this formed Crater Lake). The pumice is about 75 ft deep at this point, and about 40 ft of pumice overlies the portion of the tree from which these samples came. The impression was that the tree was still very nearly in an upright position.	6389 ± 320 7318 ± 350 5938 ± 400 6327 ± 400 Av. 6453 ± 250
428	*Fort Rock Cave, Oregon.* Several pairs of woven rope sandals (figure 4) found in Fort Rock cave, which was buried beneath the pumice from the Newberry eruption in Oregon.	9188 ± 480 8916 ± 540 Av. 9053 ± 350
609	*Danger Cave I, Utah.* Charcoal, wood, and sheep-dung from Danger Cave, near Wendover.	11 453 ± 600
610	*Danger Cave II.* Same as No 609, wood.	11 151 ± 570
C-611 and C-635	*Danger* (*Lamus*) *Cave.* Floor of cave was dated at 11 453 ± 600 and 11 151 ± 570 years by sheep-dung and wood fragments respectively, which were found in the sand (samples 609 and 610).	
C-611	*Danger Cave III.* Charcoal from just above the sand in the lowest layers of the 15 ft deposit of garbage and debris found at the cave mouth.	9789 ± 630
C-635	*Danger Cave VII.* Charred bat guano, plant stems, and twigs from 18 to 24 in below the current surface of the pile of debris.	1930 ± 240

TABLE III (*continued*)

Sample No.	*Description*	*Age (years)*
	D. MINNESOTA, WISCONSIN, AND WYOMING	
308 365 366 536 537	*Two Creeks.* Wood and peat samples from Two Creeks forest bed, Wisconsin. Forest bed underlies Valder's Drift (Thwaites). Apparently the spruce forest was submerged, pushed over, and buried under glacial drift by the last advancing ice sheet in this region. Thought to be Mankato in age.	
	Sample	
	308 (spruce wood)	10 877 ± 740
	365 (tree root)	11 437 ± 770
	366 (peat in which root, 365, was found)	11 097 ± 600
	536 (spruce wood)	12 168 ± 1500
	537 (peat)	11 442 ± 640
		Av. 11 404 ± 350
C-630	*Kimberly, Wisconsin (Neenah).* Glacial wood from Kimberly, Wisconsin. This consisted of a tree stump about 9 ft × 5 ft, found about twelve years ago. The site is almost in a direct line with the Pointe Beach site of Two Creeks, and is thought to be of Mankato age (*cf.* samples 308, 365, 366, 536, 537, 444, and 355–7).	10 676 ± 750
302	*Sage Creek, Wyoming (Yuma).* Partially burned bison bone with high organic content.	6619 ± 350 7132 ± 350
		Av. 6876 ± 250
	IV. SOUTH AMERICA	
484	*Mylodon Cave, Chile.* Dung of giant sloth from Mylodon Cave, Ultima Esperanza, Chile (51° 35′ S). Not associated with human artifacts, though sloth and man were found together in three caves 125 miles distant (*cf.* No 485).	10 800 ± 570 10 864 ± 720
		Av. 10 832 ± 400
485	*Palli Aike Cave, Chile.* Burned bone of sloth, horse, and guanaco, associated with human bones and artifacts.	8639 ± 450
	V. OTHER AREAS	
548	*Japanese.* Charcoal from Ubayama shell mound, about 10 miles west of Tokyo. Charcoal was part of structural remains in a house area in the bottom levels of the mound. Thought to be oldest house site in Japan.	4850 ± 270 3938 ± 500
		Av. 4546 ± 220
603	*Late Jomon.* Charcoal from the early Late Jomon (Horinouchi Stage) Horizon at the Ubayama shell mound (*cf.* No 548), Japan.	4513 ± 300
C-613	*Zimbabwe.* Large log from the famous prehistoric site of Zimbabwe in southern Rhodesia. Zimbabwe is generally thought to date from the fourteenth or fifteenth centuries A.D., but may be as early as the ninth century A.D.	1415 ± 160 1344 ± 160 1271 ± 260
		Av. 1361 ± 120
C-669	*Chalan Piao Site, Saipan Island (Saipan).* Oyster shell found 1·5 ft below the surface at the Chalan Piao Site, about ½ mile inland from the shore line. Conjectural date, 3000–4000 years.	3479 ± 200
C-721	*Blue Site, Tinian Island (Tinian Blue Site).* Shell (*Tridacna*) from the Blue Site on Tinian in the Marianas Islands, from Test A at a depth of 1·9 ft.	1098 ± 145

All published dates are contained in the references 9, 11, 12, and 13.

agreement is satisfactory. These exceptions may be acceptable statistically and we need not dwell on them in this short article. One of the most interesting of the 'knowns' is the redwood sample. This giant tree apparently has heartwood still containing the carbon originally deposited there when the wood was formed. This result—very acceptable to most botanists, we understand—seems to be somewhat astonishing chemically. The fine filaments which constitute the cell walls, though made of cellulose molecules which of course are extremely inert, have been bathed for thousands of years with enzymatically active sap.

The radiocarbon deposited at the beginning of history still has more than half the modern assay, so it was obviously necessary to consider how the great periods of prehistory could be used to check the method, and *vice versa*. The committee attacked this problem by setting up a network of projects so designed as to afford the maximum number of internal cross-checks. They arbitrarily excluded certain areas of the world and periods of history in order the more to concentrate, temporally and geographically, the prehistoric problems being investigated. They then assembled a team of collaborators in geology and archaeology, who proceeded to furnish samples for the study. The results now number nearly 400, including those obtained at other laboratories, though the committee has been advisory to our group alone. It is impossible in this short review even to list all the dates, but some of the more interesting ones are given in table III.

It is somewhat difficult to judge the significance of this group of dates. It seems that one of the principal conclusions is that the ice last covered both North America and Europe some 11 000 years ago. We see this in the Wisconsin Two Creeks Forest results (sample numbers 308, 365–6, 536–7 and C630), and in the European dates 337 for Germany, 355 and 356 for Ireland, and 444 for England. It would seem that there is some evidence that the northern regions of Europe and of North America were covered simultaneously.

It is interesting that, according to radiocarbon evidence, the earliest men in North America, Britain, and Denmark appeared roughly contemporaneously some ten thousand years ago. We were afraid that we should find man older than the last ice age, and had agreed that this would constitute sufficiently conclusive evidence to discredit the whole method; we felt that glaciers sweep very clean and that there should be no evidence of earlier human occupation left. So in England, which was completely glaciated, there should be no evidence of human beings older than the time of the last ice sheet. One notes that the Lascaux cave (Dordogne), sample 406, apparently was occupied, and that its paintings were executed, some 5000 years before the last ice sheet. Other samples not listed have revealed the existence of man around the Mediterranean basin long before the last ice sheet. Such evidence has not appeared in the Americas. This may of course be a fortuitous circumstance, but it does seem significant that abundant evidence of the 10 000-year threshold appears.

The ultimate question of the validity of the absolute dates given by the radiocarbon method is not yet completely answered. The evidence seems to be somewhat favourable, but only the passage of time, with its further accumulation of dates and its further digestion of the results obtained, can furnish us with a final answer.

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Jean Picard and his circle

A. ARMITAGE

The achievements of Jean Picard added lustre to the earliest years of the Academy of Sciences and the Paris Observatory. A pioneer in the use of the filar micrometer, he was also one of the first to develop telescopic sights, which he employed in geodetic operations to determine the size of the Earth with unprecedented accuracy. While in quest of the longitude of Tycho Brahe's former observatory, Picard made another notable discovery, that of the young Danish astronomer Ole Rømer, whom he launched upon a fruitful scientific career.

Among the most significant developments in seventeenth-century Europe was the rise of the scientific societies in which the pioneers of the new experimental philosophy banded themselves together for co-operative research. Two of these organizations, the Royal Society of London and the French *Académie Royale des Sciences*, attained lasting pre-eminence, and it is with one of the outstanding personalities of the latter foundation that this study is chiefly concerned. Jean Picard was the central figure of a group of inventors and observers, some of them drawn from beyond the frontiers of France, whose achievements greatly advanced precise astronomy during the later decades of the 'century of genius.'

Of Picard's life-story little is known beyond what is to be gathered from his published works. He was born at La Flèche, in Anjou, on 21st July, 1620. He took orders and bore in later life the titles of *Abbé* and *Prieur*. His earliest role in science seems to have been that of assisting in the astronomical observations of Pierre Gassendi (or Gassend), famous in the history of thought for his attempt to revive, in a Christian setting, the ancient doctrine of atomism. Although Gassendi himself could claim no notable astronomical discovery, for many years he continued the practice of methodically observing all classes of celestial phenomena. More than one operator was required to handle the cumbrous instruments of those days, and in his journal of observations, under the date 21st August, 1645, Gassendi records a solar eclipse which he observed with the assistance of 'the studious and learned Joannes Picardus of Anjou.' The budding astronomer is mentioned again for services rendered at lunar eclipses in 1646 and 1647 [1], but Picard's most productive years were those which he spent, when past middle life, as one of the distinguished company of the Academy of Sciences.

Among his schemes for enhancing the glory of France, Colbert, the prime minister of Louis XIV, had included the creation of an institution designed to embrace all branches of learning. However, various specialist groups preferred to form associations of their own, leaving a mixed band of mathematicians and physicians (which included chemists and naturalists) to constitute, in 1666, the new Academy of Sciences appointed to meet regularly in the Royal Library [2] (figure 3). Among the pioneer Academicians, Picard and two others, Auzout and Huygens, seem to have formed a closely knit group with predominantly astronomical interests. Adrien Auzout, a native of Rouen, had already played a prominent part in the informal discussion groups which had been a feature of Parisian intellectual life for a generation, and he rivalled Picard in attainment. Christiaan Huygens, one of the greatest scientists of the day, was well known in Paris from previous visits when he arrived there by invitation from his native Holland in the foundation year. These three used at first to observe the heavens from the gardens of the Royal Library. The annals of the Academy and the *Histoire Céleste* covering these early years (1666–85) have much to tell us of the problems and technical experiments that preoccupied Picard and his colleagues [3].

Much attention was devoted to the accurate measurement of the apparent diameters of the heavenly bodies. It was for work of this kind that the filar micrometer was introduced, in a form not essentially different from that which it assumes today. It appears to have been independently invented by Hooke and by Auzout, who both described it in 1667, but Picard had a share in the development of the design and became expert in its use. The instrument consisted of two metal frames, each carrying a number of parallel hairs, one frame sliding over the other in the common focal plane of the object-glass and eye-piece of the telescope to which the micrometer was fitted. This

frame was moved by turning a screw. In order to measure, say, a planetary disk, the image of the latter was confined between two hairs (one from each set), the distance between the hairs being expressed as so many turns of the screw and some fraction of a turn, these arbitrary units being subsequently converted into angular measure [4]. Picard and Auzout made almost daily use of the micrometer to measure the angular diameters of the Sun and Moon, protecting their eyes with coloured or smoked glasses. It had been a favourite exercise of Picard's master, Gassendi, to investigate how refraction affects the Sun at various meridian altitudes, and the Parisian astronomers were among the first to recognize that this factor is operative right up to the zenith, not ceasing at some arbitrary altitude as had formerly been supposed. On the other hand, the results of measuring the Moon's angular diameter throughout an entire lunation tended to undermine the currently accepted lunar theory. Eventually, the Academy became dissatisfied with all existing astronomical tables, and resolved to construct new ones from fundamental observations. The ambitious programmes of observation drawn up by the Academicians created a demand for instruments capable of measuring angles (larger than those amenable to the micrometer) with much greater precision than had hitherto been possible. This want was supplied by Picard's use of telescopic sights, which increased the accuracy of observation some sixty-fold. Such sights had been suggested by Hooke about 1665, and he says that in that year he was using an instrument of Sir Christopher Wren's invention, with telescopic sights, for examining the motion of a comet. It is possible that Picard had not heard of Hooke's work, and that the telescopic sights he used were of his own invention.

Earlier workers had been accustomed to measure celestial angles by means of instruments typified by a large graduated circle or arc, carrying a radial pointer, or alidade, which they directed towards any selected object with the aid of a pair of primitive sights. For these sights Picard substituted a telescope equipped with crossed hairs in the focal plane, thus greatly reducing the uncertainty with which the directions of objects could be defined and the angles between them measured. It now appears that this revolution was effected in two stages [5]: first, the use of a pair of convex telescope lenses which were attached to (or substituted for) the sights of the older type of instrument; and next, when these were seen to constitute a tubeless telescope, the attachment of a complete telescope, tube and all, to the instrument, with two hairs crossed at the common focus. One obvious application of this invention was to fix such an instrument to a wall with its graduated arc in the plane of the meridian, and to utilize it for taking the time and the altitude of meridian transit of celestial objects. Picard indeed asked the authorities to set up a meridian quadrant for him, but, according to Grant's 'History of Physical Astronomy,' the request was not fulfilled.

Astronomical measuring instruments could now be made much smaller than formerly, to fit telescopes two or three feet in length. The first of them were ready by early in 1669, and it was, significantly, in that year that Picard set about obtaining an improved estimate of the length of a degree of meridian on the Earth's surface, a quantity from which the size of the Earth can be immediately deduced [6].

Picard followed the classic procedure of determining the meridian zenith distance of a selected star (in Cassiopeia) from each end of a meridian arc of measured length; the difference between the two angles (giving the difference of latitude of the two observing stations) bore the same proportion to 360° as the length of the arc bore to the Earth's circumference, which was thus calculable. Applications of this method had been made by Greek and Muslim astronomers; an added refinement was introduced early in the seventeenth century by the 'Dutch Eratosthenes,' Willebrord Snell, who, instead of actually measuring his meridian arc, ascertained its length indirectly by connecting it trigonometrically with a short, accurately determined base-line [7].

The essential advance achieved by Picard lay in his pioneer use of telescopic instruments to survey his arc, and to find the difference of latitude between its terminal points. The arc selected, some 80 miles in length, lay in the plains of north-eastern France; it was connected by triangulation with a carefully measured base-line. Picard's fundamental instrument was a telescopic quadrant serving to measure to the nearest minute the angular separation of two distant landmarks or signal-fires (figure 2). To measure the zenith-distances, he employed an early form of zenith-sector. The work occupied most of 1669 and 1670, and the final result gave one degree of meridian as corresponding to about 69·104 English statute miles.

Very shortly after the foundation of the Academy, Picard and his colleagues had become

FIGURE 1 – *The Royal Observatory of Paris (from P. C. Le Monnier, 'Histoire Céleste.' Paris,* 1741).

FIGURE 2 – *Surveying with the telescopic quadrant (from 'Mesure de la Terre.' Paris,* 1671).

FIGURE 3 – *The* Académie Royale des Sciences *in session (from 'Mémoires pour servir à l'histoire des animaux.' Paris,* 1671).

Illustrations by courtesy of the British Museum.

painfully aware of the inconveniences of their garden observatory, and the King had undertaken to provide them with a permanent establishment. The erection of the Paris Observatory was inaugurated with great ceremony in 1667, and the building was virtually completed by 1671 (figure 1). By the time the Observatory was in commission, the leadership of the Parisian school had largely passed from Picard, owing to circumstances connected with the solution of another fundamental problem confronting astronomers and navigators in his day—that of determining longitude.

This operation was still customarily performed by noting the local time of occurrence of some celestial event that had been predicted in the standard time of the prime meridian; the difference between the local and standard times then gave the longitude of the observer. Galileo had proposed to utilize the almost nightly eclipses of Jupiter's satellites by their primary. This idea had been taken up by the Italian astronomer Giovanni Domenico Cassini, who in 1668 had published an ephemeris of the satellites with this purpose in mind. In the same year Picard, in Paris, was acquiring practice in timing the eclipses of these objects, taking advantage of the pendulum clocks and large telescopes at his disposal. He was astonished at the accuracy of Cassini's tables, and it seems to have been at his recommendation that Colbert took the momentous step of inviting the Italian astronomer to Paris. Cassini adopted French nationality and spent the remaining forty-three years of his life at the Observatory, upon whose fortunes he and his descendants exerted a controlling influence down to the era of the French Revolution. The astronomers of the Academy had a special motive for interesting themselves in the problem of longitude. They were anxious to know the longitudes and latitudes of the principal observatories of former days, so that observations recorded at those institutions could be reduced to the meridian of Paris for comparison with the results of work in progress there. With this object in view, Picard was sent in 1671 to Tycho Brahe's old observatory of Uranienborg, on the island of Hven in the Danish Sound [8]. Accompanied by an assistant, he travelled through Holland and, after a stormy voyage to Hamburg, came to Lübeck and thence to Copenhagen. He ascended the Round Tower which King Christian IV had built as an observatory for Tycho Brahe's former assistant Longomontanus, and early in September he crossed over to Hven accompanied by the young Danish astronomer Ole Rømer. They found the enclosure which marked the foundation of Tycho's historic observatory filled with the decaying carcases of animals. As the severity of the climate began to affect Picard's health, he withdrew to Copenhagen and completed his task by observing from the Round Tower, which was within sight of Hven. To find the difference of longitude between Uranienborg and the Tower, an observer with telescope and clock was posted at each station to time the meridian transit of Vega, and the clocks were then compared with the aid of a fire-signal. Meanwhile, eclipses of the first satellite of Jupiter were timed at Copenhagen and Paris (where Cassini had been carrying on concerted observations), and, from a comparison of all the data, the longitude of Uranienborg relative to Paris was estimated to within about ten minutes of arc.

In discussing the results of his expedition, Picard alludes to certain annual fluctuations in the meridian altitude of the Pole Star which he had noticed over the previous ten years or so, and for which he could not account by reference either to refraction or to stellar parallax [9]. In the following century James Bradley succeeded in explaining them on his novel hypothesis of the aberration of light. The first step towards Bradley's achievement was the discovery of the finite velocity of light; this was made by Picard's young Danish assistant, Rømer, who had accompanied the French astronomer on his return to Paris, and whose famous discovery of 1676 was the fruit of his close study of the vicissitudes of Jupiter's satellites, undertaken during his association with the Academy.

In his generous commendation to the ruling powers of such men as Cassini and Rømer, whom he might so naturally have regarded as formidable rivals, Picard manifested a freedom from envy and self-seeking which stands out as the most distinctive trait of a somewhat shadowy personality.

It was Picard to whom the publication of the *Connaissance des Temps* (the forerunner of the 'Nautical Almanac') was due. The first issue, which he compiled himself, was published under royal patent in 1678–9. It gave the times of rising and setting of the Sun and Moon for Paris, Calais, Lyons, and Marseilles; information about eclipses; positions of the planets at five-day intervals, and of the Moon for every day; the equation of time; tables for stellar refraction; and other information. This publication became immediately known and used in England. The British 'Nautical Almanac' was first published for the year 1767.

The revolution in methods of determining longitudes suggested the project of constructing an improved map of France. Beginning in 1679, Picard and the mathematician Philippe de la Hire found themselves engaged, by royal command, in geodetic operations which carried them through the length and breadth of the country. In the course of these peregrinations, Picard met with an accident and fractured one of his legs; thereafter his health failed. He was present at a royal visit to the Observatory in May, 1682, and he observed an eclipse in the following August, but on 12th October, 1682, he died [10]. No portrait of Picard appears to have come down to us, but E. C. Watson has shown that the astronomer is probably represented by the capped figure, third from the right, in Le Clerc's engraving here reproduced as figure 3 [11]. Most of Picard's observations were published by Le Monnier in 1741, and his papers, set in order by his friends, appeared with the other works of the old Academicians [12].

The deaths of Picard and Colbert, and the departures of Huygens and Rømer for their native lands, all occurring within a few years, brought to a close a brilliant chapter in the history of French astronomy. The Academy languished until the end of the century, when it was completely reorganized; the Observatory had to wait more than a hundred years for independence and endowment. However, the schemes and inventions of Picard and his circle did not suffer neglect. His Earth-measuring enterprise was expanded after his death with the prolongation of his meridian arc across the whole of France. The resulting controversy concerning the figure of the Earth was the occasion for the celebrated geodetic expeditions to Lapland and Peru (Ecuador). Meanwhile Rømer, after his return to Copenhagen, had set up observatories on the Round Tower and elsewhere, and had equipped them with novel instruments, in the design of which the inspiration of Picard's genius is apparent; they included a transit instrument with illuminated cross-wires, a meridian circle, an equatorial, and an altazimuth. These were but the first-fruits of the vast proliferation of instruments of precision tracing their origin back to Picard's first application of the telescope to the astronomical quadrant. Well might Condorcet in after years declare that the 'useful occupations' of Jean Picard would still be found bearing interest when the lapse of ages should have effaced his very name from human memory.

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The Zoological Station at Naples

REINHARD DOHRN

For scores of biologists the world over, the *Stazione Zoologica di Napoli* has an attraction like that of the magnet for iron. A research laboratory of the first rank, it is well equipped, beautifully situated, and naturally endowed with the abundant fauna and flora characteristic of the Bay of Naples. It is something much more: in a Europe physically and mentally scourged by two world wars it is an international oasis where biologists from many countries mingle freely and discuss their investigations, their theories, and their common interests.

The international atmosphere of the *Stazione Zoologica di Napoli*, which is probably the first characteristic to impress the stranger newly arrived from abroad, is no recent development. When Anton Dohrn (1840–1909) realized his ambition to found a laboratory by the sea two ideas were uppermost in his mind. His laboratory was to be a place where the occupants would be free to concentrate their whole efforts on scientific research, untroubled by teaching and other extraneous cares, needing only to ask in order to receive whatever material was required for the prosecution of their work: and this was to be the natural birthright of scientists of all nations.

One cannot but admire the nobility of Dohrn's vision: still less can one fail to admire its realization in bricks and mortar, and in the intangible spiritual endowment which has been nourished and fostered from the early seventies of the last century to the present day.

Anton Dohrn's father was a man of wide interests, which the prosperity of his sugar-beet business in northern Germany afforded him the leisure and means to pursue. His home at Stettin everywhere showed evidence of his versatility, from the library, with his own translations of Spanish dramas and assemblage of Scottish folk-songs, to the collection of beetles justly renowned among contemporary entomologists. The young Anton's early interest in natural history, nurtured in such a home, matured into a consuming passion for zoology—the conventional sequence in the lives of so many biologists. Like many other men of his time, his imagination was fired by the work of Darwin: had he remained conventional he would have established himself in some German university, there to study evolution in the animal group of his choice. He wanted to work with marine organisms, and, following tradition, he might have stored material collected on expeditions and left it to be worked through later at his home base. But Dohrn was unconventional: he wanted to work with living marine organisms, and this meant working at a laboratory by the sea.

Finding nothing to suit his requirements in Germany, he was drawn by the fame of Darwin and Huxley to seek advice in England, where his father was able to give him letters of introduction to fellow entomologists. Through such contacts, a Glasgow business man and amateur biologist, David Robertson, offered him hospitality at his small private laboratory on the Clyde. The stimulus of working there, together with the helpful interest of such men as Huxley, Balfour, and Ray Lankester, confirmed his intention of founding a public marine biological laboratory to meet a rapidly growing need. He later found similar interest and assistance in other European countries, after he had settled on a suitable site on the shore of the Bay of Naples. Here the fauna and flora are considerably richer in variety than are those of the north Atlantic or North Sea, and climatic conditions are such that material can be collected throughout the year.

Anton Dohrn sank his personal fortune in the venture but it was insufficient, so an aquarium open to the public was built and the daily proceeds helped to swell the fund. Of much greater significance was the establishment of 'working-tables,' whereby countries and institutions earned the right to send their scientists to work at the *Stazione Zoologica* by payment of an annual rent. This device secured a double benefit: the capital outlay and running costs of the laboratory were assured and so was its international character, since all countries making financial contribution were naturally interested in its welfare. Here, then, we have a picture of the *Stazione Zoologica* at the turn of the century: founded by a German, situated on Italian soil, and supported financially by Britain, Belgium, Germany, Italy, Russia, Austria, Hungary, America, Switzerland, and other countries.

The laboratory started as a rectangular two-storey building. Below were the show aquarium, and the *conservazione*, where daily supplies of animals and plants were received to meet the current requirements of the research workers. Above were the library, and the individual research 'tables' housed in one large laboratory. Here worked many of the great biologists of the day: Ray Lankester, Balfour, Boveri, Kowalewsky, Metchnikoff, Shipley, Hubrecht, van Beneden, Conklin, J. H. Parker, Driesch, Herbst, and T. H. Morgan, and the *corpus* of biological knowledge was much enriched by their work. Many noteworthy discoveries have been made at Naples; among them may be mentioned the respiratory enzymes of Warburg, the demonstration of neurofibrils by Apathy, and the steady elucidation—still continuing—of the fertilization and embryology of the sea urchin, pursued by generations of workers. In this last connection, it should be mentioned that the *Stazione Zoologica* is in the happy position of being able to provide mature sea urchins during most of the year. A further significant contribution by the Naples station to biological science during the last two decades of the nineteenth century lay in the field of microscopical technique. In those years, when Paul Mayer was a member of the staff, hundreds of zoologists profited from the great experience and ingenuity of this master technician, and left Naples more adept in the use of both microscope and microtome.

The *Stazione Zoologica* was not a private preserve for established biologists only: many a raw student, newly graduated, had the pleasure of making at Naples his first contribution to scientific knowledge, stimulated by the company about him, by the great profusion of research material, and, not least, by the entrancing loveliness of the Bay. For many a young student from the north of Europe the first visit to the south of Italy must have been something of a revelation. In a climate where so little effort seems necessary for the mere act of living, so much more effort can be devoted to the pursuit of science.

The fame of the *Stazione Zoologica* spread quickly, and the building was enlarged twice (in 1886 and 1904) to accommodate the increasing number of biologists wishing to avail themselves of its facilities. The extensions added a number of individual research rooms, large physiological and chemical laboratories, and rooms for other specialized purposes. The old main laboratory was meanwhile converted to house the periodicals of the rapidly expanding library. Not least important, the building incorporated an eastward-facing balcony where, in summer, the daily midday meal is now served. When he *Stazione Zoologica* was first built a beach ran down from its walls direct to the sea. In 1878, however, an embankment was raised along the sea-front, and a wide carriage-way was constructed above the beach, while the immediate environs of the *Stazione* were transformed into a park. From the luncheon balcony one now looks out over an expanse of palms and flowering trees and shrubs.

When Anton Dohrn first planned the laboratory a biologist needed little apparatus in order to conduct worth-while research. Each room had a small aquarium with circulating sea-water, a bench, and a sink. These, with the addition of a microscope, a few chemicals, and glassware met most workers' needs. The *Stazione Zoologica*'s great pride was its ability to furnish at all times of the year a wide range of living marine organisms collected daily by local fishermen specially trained and employed for this purpose. The Neapolitan dialect is rich and flexible, and rapidly acquired phrases to specify in other than scientific language the most strange and unusual creatures. Many of the Neapolitan fishermen have become exceedingly skilled at their work, and one in particular, Salvatore Lo Bianco, made a name for himself in the world of biology far beyond the confines of Naples.

Time has not stood still within the *Stazione*. Modern biologists are much more demanding in their requirements than were their forerunners, but the laboratory has been singularly successful in keeping pace with these demands. Ideas and suggestions coming from visiting specialists from all over the world have been, and are, translated into materials and means so far as finances will allow. In recent years the extension of biochemical and biophysical techniques in biology has necessitated the installation of rooms having constant temperature and humidity, and the purchase of much special apparatus for delicate and precise measurements of various kinds. The fields of biophysics and biochemistry have profited greatly by the use of the comparative method, in which the experimenter puts the same question to a number of different kinds of organisms. The *Stazione Zoologica* has been very much to the fore in research of this kind: work on the properties of a variety of respiratory pigments, and on the nature of the electrical tissue of *Torpedo* in relation to muscle and nerve chemistry, may be

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FIGURE 1 – Galathea strigosa, *the squat lobster.*

FIGURE 2 – Octopus macropus *walking among rocks.*

FIGURE 3 – Scorpaena scropha, *the rock-perch or scorpion-fish.*

FIGURE 4 – Pecten jacobaeus, *the scallop. Close-up of the mantle-edge, where the simple eyes may be seen as white spots.*

FIGURE 5 – Pecten jacobaeus, *a general view.*

(From typical photographs taken at the

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GURE 6 – Pagurus arrosor, *a hermit-crab. The astropod shell in which the animal is living is almost vered by two sea-anemones.*

GURE 7 – Loligo vulgaris, *the squid, swimming forards.*

GURE 8 – Sepia officinalis, *the cuttlefish, copulating. he male is on the right and shows the intense zebra-pattern aracteristic of courtship and copulation.*

GURE 9 – Beroë forskåli, *the sea-gooseberry. Bands swimming-plates can be seen.*

GURE 10 – *Various echinoderms, both starfish and seachins.*

Zoologica di Napoli.)

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cited as examples. Further, great advances in biochemistry and biophysics have often followed the discovery of organisms specially suitable for particular experiments: thus one may point to the use of giant axons of squids for investigating the mode of propagation of the nerve impulse. It is somewhat incongruous that whereas marine organisms are frequently better suited for particular fundamental investigations than are the conventional laboratory animals, such as frogs and rabbits, nevertheless the great majority of well equipped biological laboratories are situated inland. To this rule the *Stazione Zoologica* is a conspicuous exception.

FIGURE 11 – *The* Stazione Zoologica, *Naples.*

The task of steering the institution through two world wars has not been an easy one. In time of peace an international organization may appear strong, only to crumble overnight on the approach of war. During and immediately after the first world war there was a grave threat to the international status of the *Stazione Zoologica*; but fortunately for the world of science the original spirit in which the institution was born prevailed, and the laboratory survived as a centre of friendship between nations. During the second world war the *Stazione Zoologica* miraculously escaped significant material damage, though many bombs dropped in the surrounding park and a sea-mine exploded on the embankment hard by. There remained, however, and to some extent still remains, the problem of adequate international support. From 1939 to 1943 money was available only from Italy and Germany. Since 1944 the funds from other countries have slowly mounted; Britain gave a conspicuous lead in this respect, the Royal Society making an *ad hoc* grant of £1000 at a time when help was most urgently needed. It is unfortunate that the institution possesses no endowment that would help to tide over financial difficulties in the event of war. The post-war devaluation of the majority of European currencies has not been fully compensated by commensurate increases in 'table' rents, with the result that, of a total budget of £35,000 per annum, the Italian government has had to fill the breach to the extent of 50 per cent.

The post-war years have seen a steady increase in the numbers of foreign scientists working at the institution, and during 1952 there were no fewer than 132 visiting workers, including 23 from Britain. The busiest period at the *Stazione* is during the spring and early summer, when the temperature is ideal for work and the majority of marine animals reach sexual maturity. At such times the endurance of the permanent staff, whose numbers have not kept pace with the increasing numbers of visitors, is stretched to the limit to keep abreast of the daily problems and requirements. The problems are not only scientific: most visitors arriving for the first time cannot speak Italian, yet have to make their wants known to the Neapolitan laboratory stewards—who, fortunately, have considerable intuitive powers. Properly to serve the *Stazione Zoologica* one must be a linguist and travel agent as well as scientist, for the permanent staff have a considerable added responsibility in advising and informing each visitor on how to get the maximum benefit and pleasure from a stay at Naples.

Luntan' a Napule nun se pò sta' in the dialect means that having visited Naples one cannot stay away. Visiting scientists bear out the truth of the words of this old folk-song, for they return year after year. Driesch came fourteen times, Apathy even more, and J. Z. Young has already been nine times. The younger visitors to the *Stazione* are no less enthusiastic than their seniors: on them, and on their influence, will fall the responsibility for upholding the internationalism which is its cherished tradition.

Hardness of solids

D. TABOR

Hardness has often been considered as a rather nebulous, not to say mysterious, property of solids. Recent investigations, however, have shown that the indentation hardness of a metal is fairly directly related to its plastic yield-stress. Moreover, extension of this work provides a very simple physical explanation of the familiar Mohs scratch-hardness scale for minerals.

I. Indentation Hardness of Metals

In an introductory essay to his book on the hardness of metals, O'Neill [1] wisely remarked that hardness 'like the storminess of the seas is easily appreciated but not readily measured.' In general, the hardness of a solid is assessed in terms of its resistance to local deformation. We may estimate this in several ways. The most common method in metallurgical work is to press a hard indenter into the surface: a soft material suffers a large indentation, a hard material a small one. We may carry this a stage further, and calculate the mean pressure existing between the indenter and the solid when the indentation is formed; the result so obtained provides a quantitative measure of the hardness of the solid. The values are usually expressed in kg/mm^2; typical values are 4 for lead, 50 for annealed copper, 150 for mild steel, 900 for ball-race steel, and 1500 for tungsten carbide. It is clear that, with metals at least, indentation hardness measurements are primarily a measure of the plastic properties of the metal. Some change in the size and shape of the indentation occurs when the indenter is removed, as a result of the released elastic stresses, but the overriding effect is the plastic flow of the metal around the indenter. Consequently we may expect to find some sort of relation between the indentation hardness and the plastic properties of the metal under examination.

BASIC PLASTIC PROPERTIES OF METALS

Consider the behaviour of a cylindrical specimen of metal subjected to uniform tension along its axis. If we plot the true stress against the linear strain we obtain a straight line, the slope of which is the Young's modulus of the metal (figure 1, portion OA). Over this range the deformation is reversible, and on removing the stress no detectable residual deformation is observed. If, however, the specimen is stretched too far, the stress-strain curve deviates from the elastic curve, and on removing the stress some residual deformation remains: plastic deformation is said to have occurred. The stress Y producing plastic deformation increases as the strain ε is increased. This is part of the general observation that as metals are worked or deformed they grow harder and stronger. Over a limited portion of the stress-strain curve the increase of Y with ε can be represented in a very crude way by a relation of the type $Y = b\varepsilon^x$, where b is an empirical constant, and a similar expression holds if the metal is compressed plastically between 'frictionless' anvils. The index x is sometimes called the work-hardening index; it has a value ranging from zero for metals which do not work-harden to about 0·6 for fully annealed metals capable of undergoing very marked work-hardening.

If the tensile specimen is deformed up to D and the load is removed, the specimen recovers elastically to the point O′, where OO′ is the amount of permanent or plastic deformation. If this work-hardened specimen is now subjected to a renewed tensile test with the point O′ as the new origin,

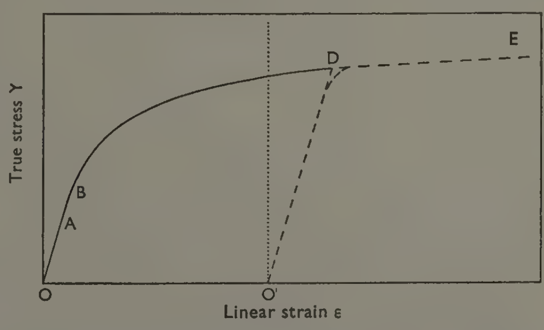

FIGURE 1 – *Stress-strain curve for a metal under tension. OA represents the initial elastic deformation. At B, plastic deformation begins. As deformation proceeds there is a steady increase in the yield stress. At D, if the stress is removed the stress-strain curve follows the reversible path DO′, and OO′ is the residual plastic extension. If the specimen is now subjected to further extension so that O′ becomes the new origin, the stress-strain curve follows the path O′DE. The yield stress now shows little increase with increasing strain.*

the stress-strain curve follows the curve O′DE, i.e. the yield-stress Y is almost constant. This means that if an indentation is made in a material in this condition any work-hardening produced by the indentation process itself will have a negligible effect on Y. We may thus expect a relation between Y and the indentation hardness.

INDENTATION OF IDEAL PLASTIC MATERIALS

A material for which Y is constant is called an ideal plastic material. The first theoretical treatment of the indentation of such a material was made over thirty years ago by Prandtl [2], and independently by Hencky [3] a few years later. Their analysis followed from the general observation that hydrostatic pressure itself plays no part in producing plastic flow of metals. A cylindrical specimen that would yield plastically under a uniaxial tensile or compressive stress Y will not flow plastically if subjected to a hydrostatic pressure, even if this is considerably greater than Y; a superposed uniaxial stress of amount Y must still be applied if plastic flow is to occur [4]. This has led to the view that plastic flow is primarily determined either by a shear-stress criterion, or by a maximum shear-strain energy criterion. Prandtl and Hencky showed that when these criteria are applied to the problem of an indenter producing localized plastic indentation, nearly two-thirds of the mean pressure of contact is in the form of a hydrostatic pressure and only one-third remains effective in producing plastic flow. If P is the mean pressure between the indenter and the metal and Y is the yield-stress, then

$$\tfrac{1}{3}P \approx Y \qquad \text{or} \qquad P \approx 3Y.$$

VICKERS HARDNESS OF IDEAL PLASTIC MATERIALS

The most common type of indenter used in metallurgical hardness measurements—the Vickers indenter—is a square-based pyramidal diamond in which the angle between the opposite faces is 136° (figure 2*a*). Plasticity theory suggests that the mean yield-pressure will depend somewhat on the angle of the indenter, but the relation between P and Y will be close to that given in the above equation. This conclusion may be examined by work-hardening metals as far as convenient, until a portion of the stress-strain curve is reached where Y is substantially constant. Vickers indentations may then be made and the mean pressure P over the indentations calculated. This is given by

$$P = \frac{\text{Load}}{\text{Projected area of indentation}}.$$

TABLE I

Relation between yield-stress Y *and indentation pressure* P. (*Vickers Indenter*)

Metal	Y (*kg/mm²*)	P (*kg/mm²*)	P/Y
Tellurium-lead	2·1	6·7	3·2
Aluminium ..	12·3	39·5	3·2
Copper ..	27	88	3·3
Mild steel ..	70	227	3·2

Typical results are given in table I [5]; it will be seen that for a wide range of materials $P = 3{\cdot}2Y$. Since the Vickers hardness number H_v is defined as the ratio of the load to the pyramidal area of indentation, H_v is less than P by a numerical factor depending on the shape of the pyramid. For the standard Vickers indenter this factor is 0·9272. Consequently

$$H_v = 0{\cdot}9272 \times 3{\cdot}2Y \approx 3Y.$$

Hence the Vickers hardness number of an ideal plastic material is roughly three times its yield-stress. This astonishingly simple relation, which follows directly from the work of Prandtl and Hencky, appears to have been overlooked in hardness literature for almost thirty years. Although many other factors are involved, it remains the basic relation between the indentation hardness and the bulk properties of a metal. Further, since an ideal plastic material under tensile conditions passes its maximum nominal tensile stress T_u as soon as plastic yielding begins, Y is essentially the

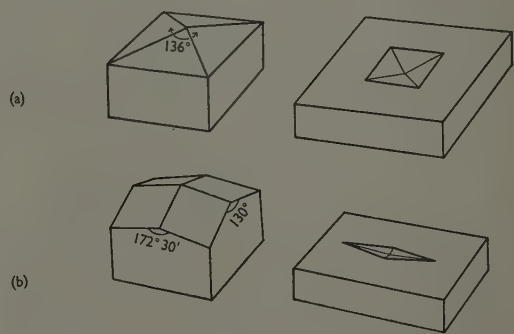

FIGURE 2 – (a) *Standard Vickers diamond pyramid indenter and the square-shaped indentation that it forms.* (b) *Standard Knoop diamond indenter and the elongated indentation that it forms. The Knoop indenter* (*p.* 31) *appears to be better suited for the indentation of brittle materials.*

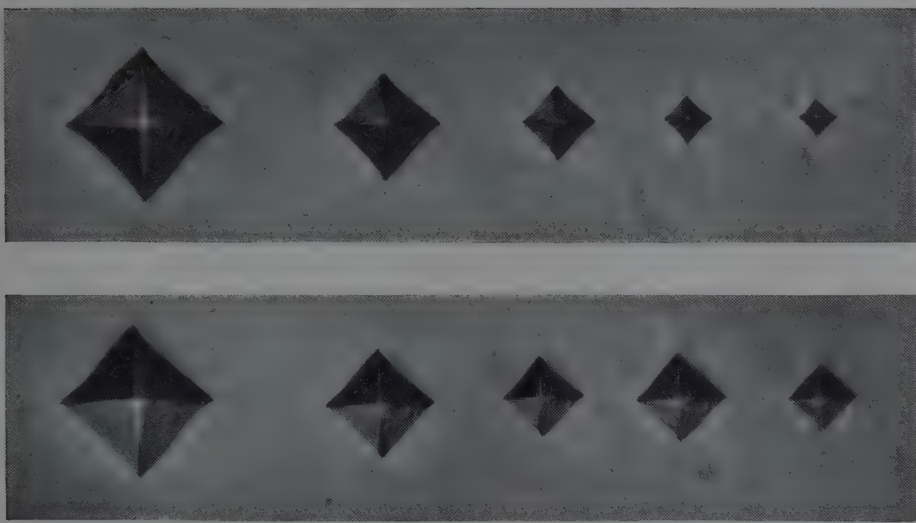

FIGURE 3 – *Indentations formed by a Vickers indenter on the surface of annealed aluminium which has been electrolytically polished. When all external vibration is eliminated and the illuminating light source switched off during loading, the indentations decrease regularly in size as the load is reduced. The hardness is essentially constant. If the illumination is maintained during loading, the vibration produced by the light source makes the indentations (for loads less than 10 g) larger than they should be; the hardness appears to decrease at small loads.* (*From Wilson* [6].)

same as T_u. Hence the hardness value gives a direct measure of the ultimate tensile strength; indeed, to a close approximation, $T_u = 0{\cdot}33H_v$.

PRINCIPLE OF GEOMETRIC SIMILARITY

It is convenient, before considering the hardness of metals which work-harden, to discuss the principle of geometric similarity. If two indentations are made of the same geometric shape, then, whatever their size, the strain distribution and the stress distribution around the indentations will be geometrically similar. This arises from basic physical considerations, and is valid whether the material undergoes work-hardening or not. In its simplest terms it implies that a large indentation is essentially a magnified picture of a small indentation, the stresses and strains being the same at any geometrically similar region. Consequently the yield-pressure, which is the mean pressure acting on the indenter, will be the same whatever the size of the indentation. It follows that for a pyramidal (or conical) indenter the hardness is independent of the size of the indentation and hence of the load. This is well borne out in Vickers hardness measurements.

This principle has a direct bearing on microhardness measurements involving the use of a pyramidal indenter. It is often found that at small loads the hardness is greater than at large loads. This is not due to a breakdown of the law of geometric similarity. It arises from the fact that the surface layers of the specimen are harder than the substrate, and that for sufficiently small loads the hardness values approach the true hardness of the surface layer, while for large loads and deep indentations the hardness approaches the bulk hardness of the substrate.

When the loads become very light it is sometimes found that the hardness appears to decrease. Recent experiments by Wilson [6] with a beam-loading type of microhardness apparatus have shown that this is due to vibration, which at very small loads makes the indentation larger than it would be if the loading were perfectly static. With the type of apparatus used by Wilson, in which the loading mechanism is supported on the stage of a standard optical microscope, it is found that, even if all extraneous vibrations are avoided, serious errors may arise from vibrations produced by the light source used to illuminate the specimen. If the light source is maintained while the indentation is made, indentations below a load of 10 g are greater in size than they should be; if the light is switched off during the actual loading operation, uniform results are obtained (figure 3). This work and other similar investigations show that

the variation of hardness with load for pyramidal indenters is due either to a genuine variation of hardness with depth or to some instrumental characteristic.

VICKERS HARDNESS AND BRINELL HARDNESS

When a pyramidal indenter is pressed into a metal, it deforms the metal plastically and work-hardens it, i.e. it raises the value of Y. The plastic strains produced will vary from point to point, and hence the yield-stress Y will also vary from point to point. We may, however, assume that there is a representative value of the yield-stress Y_r which is related to the observed Vickers hardness by the relation $H_v = cY_r$, where c again has the value of about 3. By an empirical method it is found that the indentation produces an average or representative strain ε_r (corresponding to Y_r) equivalent to an 8 per cent. tensile strain. Hence if on the known tensile stress-strain curve of the metal we determine the yield-stress for an additional 8 per cent. strain, the Vickers hardness value will be three times this value. Because of the principle of geometric similarity, this additional strain will be the same whatever the size of the indentation. It also turns out that the additional strain is roughly constant whatever the initial state of work-hardening of the specimen. This is shown in table II for annealed copper and steel specimens which were work-hardened by various strains ε_0 and had their Vickers hardness measured. The yield-stress at a strain of $(\varepsilon_0 + 8)$ per cent. was determined from their stress-strain curves and compared with the observed Vickers hardness values. The agreement between the last two columns is fairly good, and indicates that the basic assumptions are reasonably valid.

It is evident that the indentation hardness is a measure of the plastic yield-stress of the metal as augmented by the indentation process itself.

An older type of hardness measurement, due to Brinell, involves the use of a spherical indenter. Here again the indentation pressure is roughly three times the yield-stress of the metal, so that Brinell hardness numbers and Vickers hardness numbers have very nearly the same value. A fundamental difference arises, however, from the fact that indentations of various sizes formed by a given spherical indenter are not geometrically similar. A large indentation produces greater plastic strains than a small indentation, a larger increase in the effective yield-stress, and hence an appreciable rise in the observed hardness. A detailed examination [5] shows that, if d is the chordal diameter of the indentation and D the diameter of the ball, the indentation pressure P may be expressed approximately by the relation

$$P = P_0(d/D)^x,$$

where x is the work-hardening index. Thus hardness measurements with spherical indenters can provide a fairly direct measure of the ability of a metal to be work-hardened. This is an important property of a metal, for it is closely connected with its ductility.

TABLE II

Relation between yield-stress Y *and Vickers hardness number, for metals which are work-hardened by the indentation process*

Metal	*Initial deformation* ε_0 *per cent.*	$(\varepsilon_0 + 8)$ *per cent.*	$Y (kg/mm^2)$ *at strain of* $(\varepsilon_0 + 8)$ *per cent.*	cY	*Observed Vickers hardness number*
				$c = 2{\cdot}9$	
Mild steel	0	8	55	159	156
	6	14	62	176	177
	10	18	66	190	187
	13	21	67	194	193
	25	33	73	211	209
				$c = 3{\cdot}0$	
Annealed copper	0	8	15	45	39
	6	14	20	60	58
	12·5	20·5	23·3	70	69
	17·5	25·5	25	75	76
	25	33	26·6	80	81

II. Scratch-Hardness of Minerals: The Mohs Hardness Scale

Another way of estimating hardness, originally developed by mineralogists and lapidaries as a means of identifying or assessing the physical properties of stones or minerals, is the scratch-hardness test. The form of this test which has been most firmly established for more than a century is that due to Mohs [7], who proposed ten minerals in increasing order of scratch-hardness as the units of his hardness scale. Each mineral will scratch the one on the scale below it but will not scratch the one above it. At first sight it would appear that such a scale might be so arbitrary as to have no basic physical significance. Mohs

himself was aware of this difficulty, and in selecting his standard minerals for the construction of his scale he emphasizes that 'the intervals between every two members of the scale be not so disproportionate as either to render its employment more difficult, or to hinder it altogether.' With these precautions in mind, Mohs finally proposed as his ten basic minerals: 1 talc, 2 gypsum, 3 calcite, 4 fluorite, 5 apatite, 6 orthoclase, 7 quartz, 8 topaz, 9 corundum, 10 diamond. Mohs nowhere explains his criterion of perfect equality of the intervals, but he observed that the gap between corundum and diamond is greater than it should be. Recent work shows that there is, in fact, a sound physical basis upon which equal intervals can be constructed, and that the Mohs scale follows it surprisingly well.

INDENTATION HARDNESS OF MINERALS

In discussing the scratch-hardness of minerals it might seem that we are concerned primarily with the behaviour and physical properties of relatively brittle materials. This, however, is not so. The work of Bridgman [8] and others has shown that under sufficiently high hydrostatic pressures brittle materials may be prevented from fracturing, so that any deformation which they undergo under these conditions is essentially plastic. As we saw earlier, the stresses around an indenter are equivalent to a hydrostatic pressure on which is superposed a shear-stress. With many materials, these hydrostatic pressures are sufficient to inhibit brittle fracture, and very satisfactory plastic indentations may be obtained even though some cracking may occur [9]. Further, in the scratch process itself, the conditions at the contact region are similar to those around a static indenter. Here again a detailed examination shows that, although some fragmentation may occur, the deformation is dominated by the plastic flow of the material [9]. Since, therefore, both the scratching process and the static indentation process are determined primarily by the plastic properties of the material, we may expect to find some correlation between the Mohs hardness and the indentation hardness. This correlation does in fact occur, as is shown in figure 4, the data being based on indentation hardness measurements made with the standard Vickers indenter [10, 11], and also with the Knoop type of indenter [12, 13], which appears to give somewhat less cracking of brittle materials (figure 2*b*). The general trend is clear. The indentation hardness rises monotonically with increasing steps for each increment of the Mohs scale.

THE SCRATCH-HARDNESS OF METALS

Since scratch-hardness involves, primarily, the plastic properties of minerals, its investigation is greatly simplified by using metals instead of minerals. A simple experiment along the following lines at once reveals the basic characteristic of a scratch-hardness scale [14]. By suitable heat-treatment, a strip of metal is rendered soft at one end and hard at the other, with a fairly uniform increase in indentation hardness along its length. Another metal specimen of uniform intermediate hardness is prepared with a sharp point at one end, and the point is dragged over the strip from the soft to the hard end. It is then found that, over the soft portion of the strip, the friction is high and the motion intermittent, and a fine chip or shaving is produced. The behaviour remains much the same as the point approaches the harder end, until at a critical hardness of the surface the friction suddenly drops to a low value and the surface damage becomes negligible. Scratching has ceased. Applying this experimental procedure as a general criterion of scratching, it is found that a point of indentation hardness H_p will scratch a surface of indentation hardness H_s only if $H_p \geqslant 1{\cdot}2\, H_s$. The reason for this is not clear, for it does not appear to depend very critically on the shape of the point. Assuming, however, that scratching just occurs when $H_p = 1{\cdot}2 H_s$, we may construct a hardness scale in which every unit is 1·2 times as hard as the preceding one. The scratch-hardness number M is then related to the indentation hardness H by a relation of the form $H = k(1{\cdot}2)^M$. Taking logarithms of both sides, we have $\log H = M \log 1{\cdot}2 + k_2$, where k_2 is another constant equal to $\log k$. Thus a plot of log H against M should give a straight line of slope log 1·2. In practice we may wish to avoid the chance of an overlapping of the units by increasing the ratio to something greater than 1·2, but the general characteristic would still be a linear relation between log H and M.

The results obtained by Winchell and Taylor, shown in figure 4, have been plotted in this way in figure 5, and it is seen that, if diamond be excluded, the relation $\log H = nM$ is surprisingly well obeyed. The value of n corresponds to a ratio of hardness between each Mohs unit of about 1·6. Thus the Mohs hardness scale gives scratch-hardness values which correspond to fairly well defined indentation hardnesses, each increment on the Mohs scale corresponding roughly to a 60 per cent. increase in indentation hardness.

This simple relationship is not surprising when

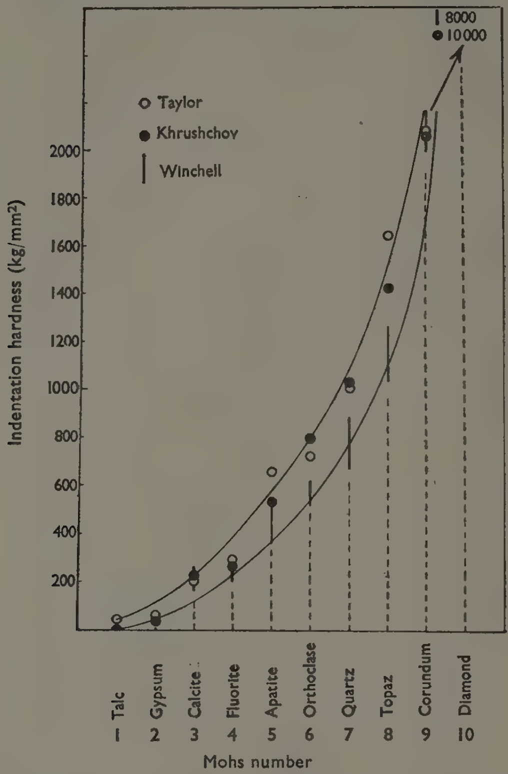

FIGURE 4 – *Relation between Mohs hardness numbers and indentation hardness values. Vickers indenter:* O, *results from Taylor* (1949); ●, *results from Khrushchov* (1949). *Knoop indenter:* |, *results from Winchell* (1945) *and Knoop* et al. (1939.)

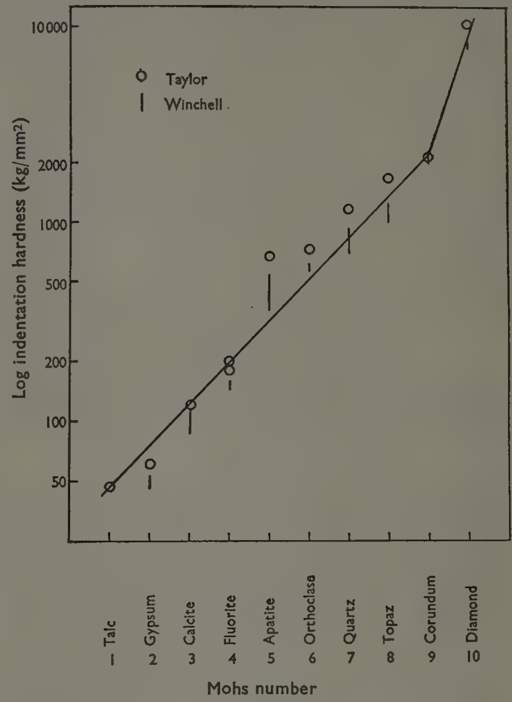

FIGURE 5 – *Mohs hardness number M plotted against log H, using the data of Taylor and of Winchell and Knoop* et al. *M is approximately proportional to log H. Each Mohs interval corresponds to an increase in indentation hardness by a factor of about* 1·6.

it is realized that figure 4 is representative of many physiological processes in which the response is proportional to the logarithm of the stimulus. It is clear that Mohs did not simply choose ten common minerals arranged in order of increasing hardness; he must have experimented with a much larger number until he had satisfied himself that he had obtained 'equality of the intervals.' His criterion was presumably a tactile one, and under these conditions the same logarithmic law apparently applies.

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Heredity in *Paramecium*

G. H. BEALE

The unicellular nature of *Paramecium* and the peculiar mechanism of its conjugation process make it an organism particularly suitable for the study of the role of cytoplasm in heredity. Experiments here described have hitherto been concerned with two systems of inheritance—the 'killer' system and the antigen system—and seem to establish that at least in *Paramecium* the cytoplasm is important in heredity, though it is too early to draw any general conclusions from this.

It is now accepted by geneticists and most other biologists that the determinants of hereditary characters, the genes, are situated in the nuclei of plant or animal cells and are arranged linearly along the chromosomes. It is, however, a fallacy to suppose that the genes have a monopoly in the control of hereditary processes, and that no other cellular constituents possess any comparable importance. Examples of cytoplasmically inherited characters have been known since the earliest days of genetics, especially in plants, but the number of such examples has admittedly been small in comparison with the gene-controlled characters.

There is obviously room for further investigation in this field, and many workers, while admitting that no cell can function for long without a nucleus, believe that materials in the cytoplasm are as indispensable as the genes for the successful development of an organism. For technical reasons, however, the role of the cytoplasm in heredity has generally been neglected in studies of the favourite subjects of geneticists, such as *Drosophila*. Consequently, in recent years some geneticists have turned their attention to other organisms more suitable for the investigation of this problem, and foremost among these is the ciliate protozoon *Paramecium aurelia*.

Individuals of *Paramecium* multiply by binary fission, whereby the daughter cells obtain nuclear constituents exactly the same as those of their parents. Samples of a population of cells derived from a single individual may easily be isolated into drops of water, and subjected to various treatments which produce more or less permanent changes. Furthermore, thanks to the discovery of the mating-type system by Sonneborn [1], matings may be made between the changed cells and those from which they were derived. Only in a unicellular organism like *Paramecium* is such a procedure possible, since in higher organisms the fertilization process involves special germ cells which are well protected from environmental variations, and can be modified only by such drastic methods as treatment with X-rays, mustard gas, and so on.

Paramecium has yet another advantage as a choice for investigation: the sexual process involves the peculiar phenomenon of conjugation, in which two individuals undergo a reciprocal exchange of haploid nuclei with little or no exchange of cytoplasm (though exceptionally, and especially under certain known conditions, large quantities of cytoplasm may be exchanged). Consequently, after conjugation the two ex-conjugants, and all the cells derived from them by fission, contain identical nuclei, half derived from one parent and half from the other. If the parents differed cytoplasmically, however, the progeny of one ex-conjugant will be expected to contain one kind of cytoplasm, and the progeny of the other ex-conjugant the other kind of cytoplasm. The organism is therefore pre-eminently favourable for investigating the relative importance of nucleus and cytoplasm in the determination of hereditary traits.

THE 'KILLERS'

It was reported in 1939 by Sonneborn [2] that certain races of *Paramecium*, the 'killer' races, exuded into the water a poisonous substance which killed individuals of other, 'sensitive,' races. The killer character was hereditary, and was determined by a combination of genes and cytoplasm. Thus if a killer animal of stock 51 (variety 4) was crossed with a sensitive animal of stock 47 (also variety 4), those ex-conjugants which received cytoplasm from the killer parent were killers and those which received cytoplasm from the sensitive parent were sensitives; where, however, there had been visible transfer of cytoplasm during conjugation, both ex-conjugants yielded killer offspring. Sonneborn therefore postulated a cytoplasmic factor *kappa* as the hereditary unit

responsible for the development of the killer character. Further work, however, showed that nuclear genes also were involved, for if killer animals of stock 51 were mated with sensitives of stock 32, and the resulting hybrids made to pass through autogamy (a process of internal self-fertilization occurring in *P. aurelia*), it was found that some animals, though they had received cytoplasm from the killer parent, were nevertheless sensitives. Simple breeding analysis showed that a dominant Mendelian factor, called *K*, had to be present in the nucleus, in addition to *kappa* in the cytoplasm, for the development of the killer character (figure 1). If the gene *K* was not present, *kappa* disappeared from the cytoplasm. Once *kappa* was lost, it could never be formed again, even in the presence of *K*, unless at least one 'unit' of *kappa* was introduced from the cytoplasm of another killer animal.

It was therefore clear that *kappa* had a considerable degree of autonomy. Furthermore, several different kinds of *kappa*, and mutation from one to another, were found to occur [3]. These and other facts made it seem likely that *kappa* was a unit somewhat resembling a gene but situated in the cytoplasm instead of on a chromosome. The term plasmagene was therefore applied to it. This aroused much controversy. Supporters of classical genetics feared a threat to the position of the nuclear gene, which might not after all be the only indispensable unit of heredity; other workers hoped that at last it had been shown that the cytoplasm was just as important as the genes.

In 1948, however, Preer [4] succeeded in making *kappa* visible. He stained killer paramecia by the Feulgen method and found that each cell contained some hundreds of Feulgen-positive particles, easily visible under the microscope, while sensitive animals contained no such particles. Furthermore, Sonneborn [5] was able, though with much difficulty, to infect paramecia with *kappa* by means of a concentrated *Brei* (mash) made from ground-up killer animals.

It therefore became possible (as had earlier been suggested by Altenburg and others) that *kappa* was not so much a cytoplasmic gene as a symbiotic organism, and not an essential part of the hereditary apparatus of *Paramecium*. Those who formed this opinion were inclined to dismiss the whole matter by asserting that *kappa* was 'only' a virus. The analogy with viruses (or bacteria) is however by no means perfect, and it is probably safest to regard *kappa* as a particle which has peculiarities of its own and is not to be identified either with

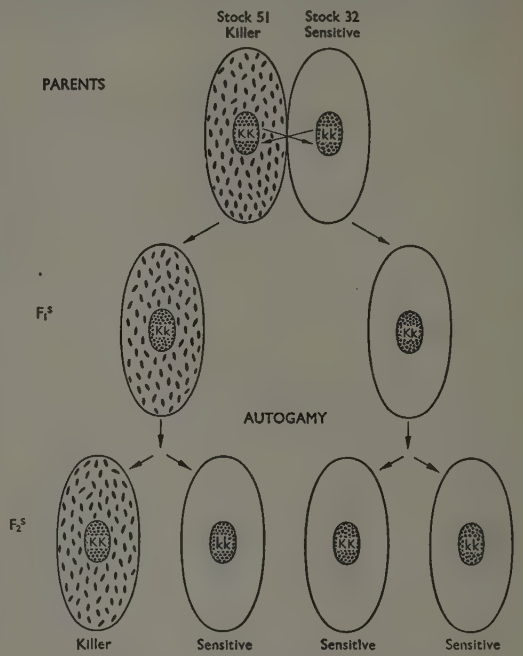

FIGURE 1 – *Inheritance of killer character.*

the genes, on the one hand, or with the viruses, on the other. Recent work by Chao [6] has indeed shown that the relationship between *kappa* and the gene *K* is remarkably precise, in that paramecia of the genetic constitution *KK* contain twice as many *kappa* particles as paramecia of the constitution *Kk*, other circumstances being the same.

It is uncertain how widespread *kappa*-like particles are in nature, apart from those occurring in various races of three out of the eight varieties of *P. aurelia*. It is well known that Feulgen-positive material is rarely found outside the chromosomes, and we may therefore be dealing with a phenomenon of only limited occurrence. Nevertheless, interesting parallels are to be found between the *kappa* particles here described and, for instance, the pro-virus particles assumed to be present in lysogenic bacteria [7].

THE ANTIGENS

It has been known for many years that if paramecia are injected into rabbits, the latter produce antibodies effective in immobilizing and killing paramecia of the same type as those injected. It has also long been known that a given sample of paramecia may contain some individuals which are completely unaffected by an anti-serum which is highly toxic to the majority. The genetical

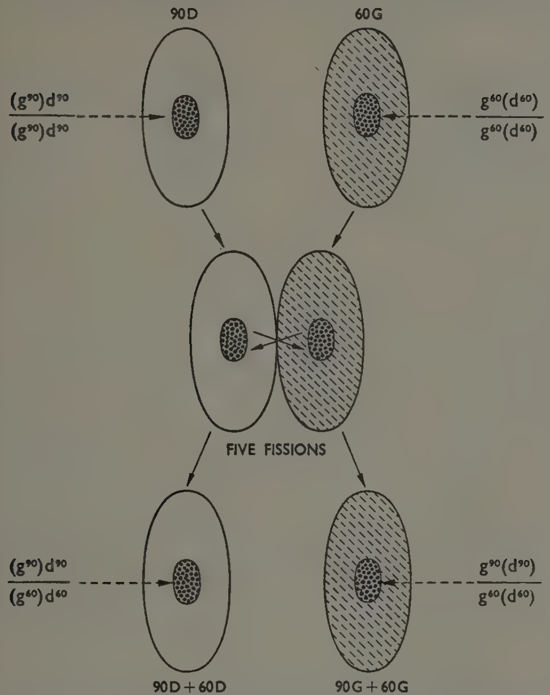

FIGURE 2 – *Inheritance of antigenic types after five fissions following cross* 90*D* × 60*G*. *Genes in brackets are unexpressed.*

aspect of antigen variation of this kind has been under investigation for some years by Sonneborn [8], Beale [9], and others.

The first remarkable fact to be discovered was that paramecia of a single stock, i.e. those which had all been derived by asexual reproduction from a single, homozygous individual, could change in a striking manner from one antigenic type to another. Thus type A might change to type B, or the reverse. Such types could be readily distinguished by their reaction to two different antisera, called anti-A and anti-B respectively. Further work showed that a whole series of antigenic types could be produced within a single stock. By 1950 as many as eight such types had been reported for stock 51, and there are undoubtedly more to be found. Each of these eight or more types contained exactly the same genes, but it was shown by Sonneborn that they differed in their cytoplasm.

Transformation from one antigenic type to another could be facilitated by a number of treatments, such as by varying the temperature or quantity of food or the salinity of the medium, or by treating the animals with a sub-lethal dose of homologous antiserum. Induction of an antigenic change by the last-mentioned treatment is of special interest, in that it would appear to be an example of a hereditary change or mutation to a type more favourably adapted to the inducing environment. Such a result is of course incompatible with orthodox genetical theory. However, it must be emphasized, first, that these directed changes in *Paramecium* are cytoplasmic, and have nothing to do with gene mutations; and secondly, that treatment with weak homologous antiserum by no means always produces such changes. Individuals recovering from serum treatment are frequently of the same antigenic type as before.

As stated above, the environment had a marked influence on the antigenic type formed. Nevertheless, more than one type could be perpetuated in different animals of the same stock under identical conditions. For example, Sonneborn and Le Suer [10] showed that in stock 51 three different types —B, D, A—could be maintained indefinitely by growing the animals at 27° C with sufficient food for one fission a day. Under such conditions the diverse kinds of cytoplasm persisted for many generations, i.e. they were hereditary. Thus it appeared that variations in the antigens were controlled exclusively by cytoplasmic factors, and that nuclear genes played no part in the system at all. However, later work by Sonneborn with variety 4, and by Beale with variety 1, showed that the genes did after all control the antigenic type in an exceedingly precise manner.

In each stock of variety 1, three antigenic types were commonly found: S at low temperatures, G at medium temperatures, and D at high temperatures. Each stock formed its own characteristic variants of these three types. For example, stock 90 formed the type 90G, while stock 60 formed the type 60G, which was serologically quite distinct from 90G. Genetic analysis showed that these two variants of the G type were determined by a pair of allelic genes, called g^{90} and g^{60} respectively. Furthermore, the high temperature (or D) types of these two stocks, 90D and 60D, were also serologically distinct, and also controlled by a pair of alleles, d^{90} and d^{60}. The *d* alleles were, moreover, at a different place on the chromosomes from the *g* alleles.

Antigenic specificity therefore depended upon which allele at a given locus the paramecium contained. For each antigenic type—D, G, S, etc.—a corresponding series of multiple alleles at three loci—*d*, *g*, *s*, etc.— was demonstrated. Every individual contained a particular allele at each of these three (or more) genetic loci.

In spite of containing genes at these several loci at one and the same time, however, an animal of a given stock showed only a single type of antigen (except in heterozygotes made by crossing animals of two different stocks, when two antigens were commonly formed in the same animal at the same time). In general, a paramecium contained antigens of type G, or of type D, but not of both types at the same time. Hence, though genes at all three loci (*d*, *g*, *s*) were present, only one of the three was expressed, that is, had any effect on the phenotype. Which one of the three was thus expressed depended upon the cytoplasm. This was clearly shown by making crosses of the type 90D × 60G, i.e. between animals differing both genically and cytoplasmically. In figure 2 the results of such a cross are represented diagrammatically. Parenthetically, it must be noted that since changes of environment readily cause the cytoplasm to change from one state to another, the situation shown in figure 2 is not final. By changing the temperature, paramecia descended from either of the conjugants may be made eventually to form antigens of either the D, or the G, or even the S, type.

To sum up this complex situation, we can say that each paramecium of each stock contains at least three (and probably many more) genes, of which each stock has its characteristic alleles conferring a specificity on the antigens. Each animal also contains cytoplasm of a particular kind, but the cytoplasm (unlike the genes) can be easily changed, reversibly, by various environmental treatments. Finally the kind of cytoplasm determines which of the three or more genes present in the nucleus are called into action (figure 3).

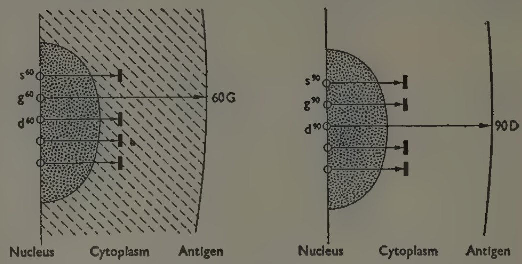

FIGURE 3 – *Diagrammatic representation of interaction between genes and cytoplasm leading to the formation of antigenic types* 60*G and* 90*D. Cross-hatched cytoplasm indicates 'G state'; unshaded cytoplasm indicates 'D state.'*

CONCLUSION

It is tempting to draw conclusions of a general nature from the two systems of inheritance here described—the killer system and the antigen system. Without doubt, both systems demonstrate the importance of both nucleus and cytoplasm in the determination of the hereditary characters. Furthermore, both systems, but especially the antigen one, can serve as models for cellular differentiation in multicellular organisms. Geneticists have for long been challenged by the fact that the cells of an animal or plant, though all (or nearly all) contain the same sets of genes, are extremely diverse. It has been usual to assume tentatively that the differences between the various cells of a single organism are cytoplasmic, but there was very little evidence for or against this view.

The two *Paramecium* models enable us to be somewhat more precise. On the basis of the antigen model we may assume that every cell of a multicellular organism contains many genes, of which only a small proportion influences the course of events in that cell. This small proportion is selected by the state of the cytoplasm in that cell. In other cells the state of the cytoplasm may be quite different, and completely different genes are called into action. The state of the cytoplasm is, partly at least, controlled by the environment. Thus through a complex interaction of genic, cytoplasmic, and environmental factors the various cells develop in different directions.

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Irradiation colours in minerals

KARL PRZIBRAM

Coloured modifications of normally colourless crystals, such as those of rock-salt and fluorspar, are occasionally found in nature. The coloration appears to be conditioned by the presence of irregularities in the crystal lattice. Similar effects may be produced by exposing the crystals to radiation, and there is a good deal of evidence, both qualitative and quantitative, that this is also the process by which the minerals become coloured naturally.

The story of the geological past of the Earth is told by the rocks that constitute its crust. One aspect of this story that we are gradually coming to understand is revealed by the colours displayed by certain minerals. It has long been assumed that some of the coloured minerals, such as blue rock-salt [1] and multicoloured fluorspars [2], owe their colour to radioactive effects. This idea led to the investigation of the effect of radioactive radiations on colourless crystals.

If colourless rock-salt is exposed to radium rays it becomes yellow (figure 1(*a*)), but the coloration is unstable, and disappears quickly if the sample is heated to temperatures between 200 and 300° C. If the initial dose of irradiation is sufficiently strong, the yellow changes to a bluish violet (figure 1(*b*)) when the yellow sample is carefully heated to approximately 200° C. A similar change to a greyish colour is observed if a yellow sample is kept in the dark for long periods, or in a shorter time if it is kept in daylight (figure 1(*c*)).

The formation of these colours was formerly explained by assuming the absorption of a radiation quantum by a chlorine ion of the rock-salt, resulting in the loss of one electron to a sodium ion, which thus became a neutral sodium atom. This process would account for the absorption of light and consequent colour-formation. The advent of quantum mechanics, and the realization that a crystal lattice always contains gaps, led to a new interpretation [3]. According to this, the colour-centre (F-centre), which in the case of rock-salt produces the yellow coloration, is an electron held in an anion vacancy, i.e. a lattice site where a chlorine ion is missing.

The belief that coloration is caused by a permanent disturbance in the crystal lattice is confirmed by the investigation of compressed rock-salt. A radiation dose which causes yellow tinting in non-compressed salt renders the compressed salt nearly black (figure 1(*d*)) [4]. There is, however, an optimal limit to which this disturbance can proceed, and at very high pressures the tendency to colour-change decreases. The blackening is due not only to a darkening of the yellow colour, but to increased absorption in the yellow and red regions, which, by itself, would produce violet and blue tints similar to those produced in the non-compressed yellow salt by heating. In fact, if the yellow-producing F-centres are destroyed by illumination, the dark colour of the compressed salt changes to blue (figure 2(*a*)). If such a blue-coloured sample is kept for fairly long periods, areas of a lighter colour will sometimes appear and gradually spread (figure 2(*a*)). It has been shown by various methods that this is due to an adjustment of the disturbance in the lattice, i.e. a recrystallization, and this observation provided an excellent method for the study of the recrystallization of compressed rock-salt [5].

On the basis of Siedentopf's classical investigations with the ultramicroscope, the blue colour of rock-salt was attributed to the presence of colloidal sodium particles. It has now been established beyond doubt that some of the blue and violet tints of rock-salt are not of this ultramicroscopic nature, but are caused by electrons situated at centres of stronger disturbance in the lattice (M- and R-centres) [6].

Before one can be certain that the natural colour of a mineral is due to radioactive effects, the following points have to be confirmed:

1. Gentle heating destroys the colour at temperatures of 200–300° C.
2. The disappearance of the colour is (very frequently) accompanied by thermoluminescence, the energy stored during irradiation being partly emitted as light energy.
3. The colour in the natural state agrees with the colour obtained by irradiation of the colourless mineral.

The further confirmation has sometimes been demanded that the coloration should be obtained under the same conditions as those prevailing in nature. This seems a rather unrealistic stipulation, especially when one considers the long periods of time during which the natural process works. The fact that in the laboratory the blue colour of rock-salt can be produced only by heating or illumination, whereas in the salt-deposits it has been formed in the dark and at ordinary temperatures, cannot be used to contest the radioactive origin of the colour. It seems quite possible that sufficiently long preservation in the dark at room-temperature might result in the destruction of the F-centres, with a consequent change of the grey colour into blue. The blue-producing centres are more stable than those producing yellow, and, under natural conditions, the low-intensity radiation acting in the Earth's crust will preferentially produce the more stable centres.

One of the arguments against the interpretation of rock-salt tints as irradiation colours was the absence of the primary yellow colour in nature. The discovery of yellow rock-salt at Hall in the Tyrol by Schauberger [7] has finally dispelled this objection. This salt shows the same behaviour as the yellow salt produced by irradiation; moreover, its absorption maximum is situated at the same wavelength of 460 μμ. The less frequent occurrence of the yellow salt, which has since been discovered in other places, is in agreement with its lower stability. The third rule in the above list is today expressed more strictly by the requirement that the absorption maxima in both salts must be situated at the same wavelength, as was confirmed for yellow rock-salt.

The three rules are also fulfilled for violet and for blue rock-salt. These lose their colour when moderately heated, and thermoluminescence can be observed. On the evidence of recent investigations [8], the violet colour in rock-salt is usually not caused by colloidal particles. This natural violet salt, like the violet salt obtained by irradiation and heating, shows an absorption maximum at 580 μμ. In the blue salt whose colour is of colloidal origin, absorption maxima vary with particle-size between 630 and 680 μμ. The same maxima are obtained with the blue salt prepared by heating in sodium vapour. The colloidal blue colour can also be obtained by concentrated irradiation with cathode rays at high temperature [9], though this is a more difficult method. Its occurrence in nature may be due to impurities promoting colloid formation; the long time-periods involved in natural processes may also play their part.

The question now arises whether the small quantities of radioactive substances existing in nature are sufficiently strong to produce mineral colours. This problem was first investigated in the case of rock-salt and fluorspar [10], and the results obtained so far seem confirmatory. Rock-salt contains uranium and radium, some β-radiating potassium, and a certain amount of helium the origin of which has been explained by Hahn [11] as follows. During the Tertiary period, salt deposits were recrystallized at great depths from strongly radioactive water containing radon. The lead and its radioactive isotope RaD which this water carried were precipitated with the rock-salt and especially with the sylvine (KCl). The RaD was transformed into α-radiating polonium which, together with its parent substance RaD, has long since decayed. The α-particles which it emitted were, however, preserved in the salt as helium atoms. The calculation of the energy changes involved in this process has been published by the author elsewhere [10]. The yellow and violet tints of the mineral could have been produced by either of these sources of radiation; the blue colour, however, cannot be due to the uranium-radium content of the mineral.

On the whole, we feel inclined to accept Hahn's hypothesis. We further assume that the special sensitiveness to radiation shown by the coloured rock-salt must have been caused by impurities and other disturbances, which would explain why not all specimens of rock-salt are coloured in spite of the fact that the content of radioactive substances does not notably differ in coloured and in colourless rock-salt. With regard to fluorspars, coloration is sufficiently explained by the uranium-radium content.

Figures 2(*b*) and 2(*c*) show two samples of blue rock-salt from Stassfurt. In the former, the blue salt marks the area of contact between colourless rock-salt and sylvine; the association of blue rock-salt with sylvine is a fairly frequent occurrence, and is probably related to the secondary recrystallization process. Figure 2(*c*) shows a blue-black rock-salt crystal surrounded by a lighter-coloured salt of more recent origin. The jagged cleavage face of the dark blue salt indicates plastic deformation, which favours colour-formation.

The violet rock-salt found in the Grimberg shaft at Heringen in the Werra region is of special interest (figures 3(*a*) and (*b*)). Here, coloration appears in stripes parallel to the cube faces, and

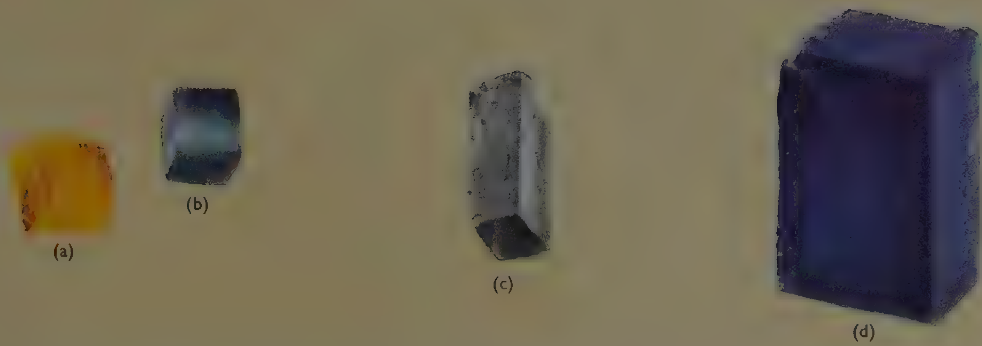

FIGURE 1 – *Specimens of rock-salt coloured by radium rays.* (a) *Recently coloured;* (b) *coloured yellow originally but turned blue by heating;* (c) *coloured yellow originally but turned grey by ageing;* (d) *compressed crystal originally dark brown but turned dark blue by exposure to light.* (× 1·5)

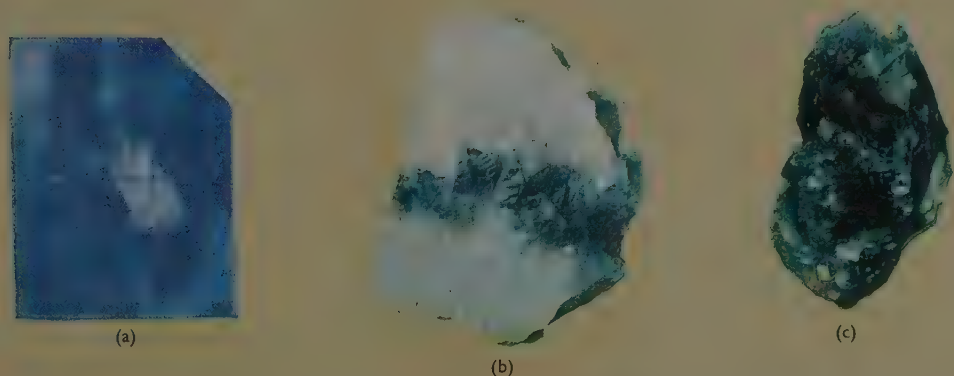

FIGURE 2 – (a) *Artificially coloured compressed rock-salt, partly recrystallized;* (b) *composite crystal of rock-salt and sylvine (Stassfurt) with blue zone marking the region of contact;* (c) *varying depth of colour in blue rock-salt from Stassfurt.* ((a) × 1·5; (b) *and* (c) × 0·2)

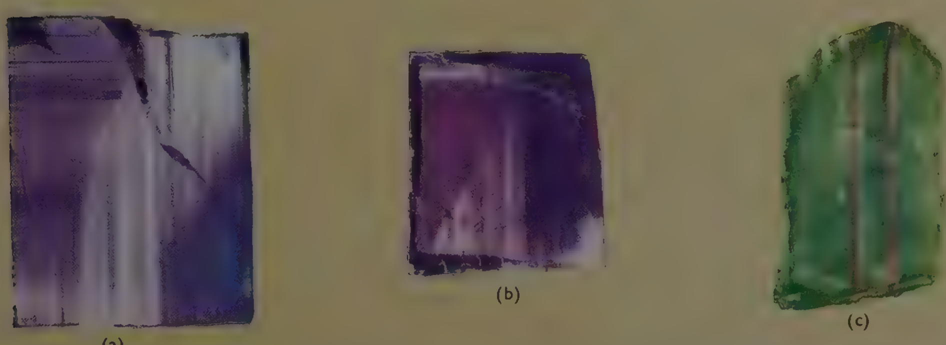

FIGURE 3 – (a) *Natural blue and violet rock-salt from the Grimberg mine, Heringen;* (b) *violet rock-salt from the same mine, the deeper coloration marking the parts which have grown most rapidly and the darker lines the rhombododecahedral glide-planes;* (c) *fluorspar from Pe-shan, China.* ((a) × 1·5; (b) *and* (c) × 0·5)

thus clearly indicates the way in which the crystal has grown [12]. If crystal growth had taken place at the same rate in the direction of both axes, the diagonal connecting the corners of the coloured growth-areas would have been inclined at an angle of 45° to the cube faces. As this is not so, growth must have taken place at an increased rate in the direction of the axis which makes the smaller angle with the diagonal. It further appears that the direction of growth sometimes undergoes sudden changes, for unknown reasons, and in this connection an interesting relation can be established: the pyramid formed by more rapid growth is usually darker and of a more bluish tint than that formed at the smaller rate. This indicates that increased growth-rates produce greater lattice disturbances, and therefore greater readiness for colour-formation. The same growth-areas can be observed in a rock-salt crystal coloured blue as a result of irradiation and suitable heating, and thus the growth of colourless crystals could also be investigated. By this method it was possible to observe that, in long prismatic rock-salt crystals from Wieliczka, sideways growth occasionally ceased completely and only the base moved forward. No satisfactory explanation of this singular behaviour has so far been advanced.

The dark stripes frequently observed in blue rock-salt at angles of 45° to the cube faces are the traces of the rhombododecahedral glide-planes of the rock-salt. These are more strongly disturbed, and consequently more deeply coloured (figure 3(*b*)).

Fluorspar shows an even greater variety of irradiation colours than rock-salt. It was the first mineral in which a colour similar to the natural coloration was artificially produced in a colourless sample. In 1830 Pearsall [13], one of Faraday's assistants at the Royal Institution, succeeded in producing pink or bluish tints in colourless fluorspar by means of the spark of a Leyden jar. The effect was probably due to the action of short-wave ultra-violet radiation. Pearsall expressed the opinion that natural coloration might be due to electrical effects, and this idea, put forward so long before the discovery of radioactivity, seems amazingly near to the modern interpretation which attributes the irradiation colours occurring in nature to the influence of corpuscular radiations (β- and α-rays).

The rules of behaviour mentioned earlier are usually fulfilled by fluorspars: they easily lose their colour and show a brilliant thermoluminescence (as has long been known), and the irradiation colours agree with the natural coloration.

Comparison of the absorption spectra of 20 different fluorspars, partly in the natural state, partly after irradiation [14], resulted in the determination of maxima at some of the following wavelengths: 335, 360, 370, 385, 400, 410, 430, 450, 470, 500, 525, 550, 580, 600, 625, and 640 μμ. The author and his collaborators [15] succeeded in tracing the well known blue fluorescence of fluorspar to the presence of bivalent europium, and a red fluorescence band to bivalent samarium. The author was of the opinion that the bivalent rare-earth ions would also influence the absorption power of the fluorspars, and that they might be responsible for the maxima at 360 to 385 μμ as well as at 430, 450, and 470 μμ. This was partly confirmed by more recent observations. Freed and Katcoff [16] discovered an absorption maximum for Eu^{++} in $SrCl_2$ at 389 μμ; Butement [17] found maxima for Sm^{++} in $SrCl_2$ at 356, 377, 412, and 480 μμ, and in NaCl at 357, 378, 412, and 470 μμ. On the basis of these results, the fluorspar maxima at 385 μμ might be due to Eu^{++}, and those at 360, 370, 410, and 470 μμ to Sm^{++}. On the other hand, Smakula [18] found absorption maxima at 335, 400, and 580 μμ in very pure synthetic CaF_2 after X-ray irradiation. These may be attributed to the colour-centres of the basic substance. As shown above, the same maxima are found in the absorption spectra of natural fluorspars. The maxima at 430, 450, 500, 525, 550, and 600 μμ and beyond are still unexplained.

Long-wave maxima might occasionally be caused by colloidal coloration. However, the deep blue colour appearing in many fluorspars after irradiation cannot be of colloidal origin, as such specimens never show the Tyndall effect. It is likely that the final spectrum of the CaF_2 centres will prove even more complex, and the long-wave maxima will probably prove to be due to centres of stronger disturbance. It is also possible that other heavy metal ions are involved. Another point which has not been fully explained is the fact that, in different types of fluorspars, one or the other maximum is more strongly apparent. This causes the varying colours and may be partly attributed to the distribution of the rare earths, traces of which are contained in all fluorspars. Their distribution is rather irregular, even within one single crystal. It has been established that crystals or crystal layers containing a relatively high percentage of samarium will quickly acquire a deep blue coloration when irradiated. Samarium thus causes increased sensitiveness, as it is

transformed by irradiation into its unstable bivalent form; this easily loses its surplus electron, which then serves to form a colour-centre. Earlier, Steinmetz [19] had noticed the increased sensitiveness caused in fluorspar by sulphide inclusions.

Figure 3(*c*) shows a fluorspar from Pe-shan, China. The uneven colour distribution is clearly apparent, showing violet stripes on a green background. The fact that the green areas display a stronger bluish fluorescence than the violet stripes indicates their higher content of bivalent europium; it was possible to show that the difference is not due to an unequal absorption of the light.

Fluorspar provides another example of the principle of natural formation of the most stable. The pure blue colour frequently obtained by irradiation is very rarely found in nature; it gradually changes into the more stable violet tint which is so often observed in natural samples of fluorspar. There is also evidence for the already mentioned relation between colour formation and lattice disturbance: when green fluorspar is compressed its colour changes to violet, a phenomenon which might be called piezochromy [20].

So far, investigations have been concerned mainly with rock-salt and fluorspar, but it seems fairly certain that a number of other minerals owe their colours to radioactive effects. We may mention smoky quartz and amethyst, as well as mica. For mica, the ability to undergo colour-change by irradiation is confirmed by the occurrence of the pleochroic halos produced by the α-rays of radioactive inclusions. Much work has still to be done in this field.

The minerals shown in the illustrations belong to the collection of the Institute of Radium Research of the Austrian Academy of Science. The fluorspar shown in figure 3(*c*) was presented by Professor Iimori, of Tokio. The reader is also referred to the author's work *Verfärbung und Lumineszenz*. Springer, Vienna. 1953.

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The chelicerae of spiders

W. S. BRISTOWE

The chelicerae or jaws of spiders are equipped with poison-glands, and legends about their bites have been widespread since the earliest times. The chelicerae have an interest far beyond that of their sinister reputation, or of their ability in a few species to do serious harm to man. Their evolution, the multiple purposes for which they are used, and the structural changes they have undergone that suit them for these purposes, all repay thought and inquiry.

The class Arachnida comprises a number of orders, including the *Araneae* (spiders), scorpions, palpigrades, phalangids (harvest-men), pseudoscorpions, solifugids, ricinuleids, acarines (mites), uropygids, amblypygids, and several extinct orders. Most of these orders were already in existence in the Carboniferous period, and we have little clear evidence as to their earlier ancestry or relationships.

Nearly all the extinct and surviving orders have chelate or pincer-like appendages on the head, called chelicerae, but those of spiders are of different design from those of the rest. In spiders, each chelicera is composed of two segments. The basal segment is thick and hard. It contains all or part of the poison gland and has limited mobility, lateral or up and down. Attached to the apical end is the fang; this is like a curved needle or a sharp thorn, near the tip of which is a tiny aperture through which the poison is extruded. When in repose the fang lies bent back along the lower or inner surface of the basal segment, often in a groove bordered by teeth.

Chelicerae of similar design are found in the extinct order *Trigonotarbi* (formerly part of the *Anthrocomarti*), and in living uropygids and amblypygids (both formerly in the order *Pedipalpi*) [12]. Although spiders and *Trigonotarbi* go back to the Devonian [6], and some of the pedipalps to the Carboniferous, it seems certain that this type of chelicera arose from the chelate or pincer form. It is not difficult to see how this development occurred (figure 1). The large tooth on the basal segment of a chelicera of the *Pholcidae* and *Scytodidae* groups of spiders is in my opinion homologous with the immovable finger of a chela. Since some arachnologists are likely to argue that the chelate appearance is accidental rather than a survival, it may be remarked that the sexual organs of *Scytodidae* and of some *Pholcidae* are not much different from those which spiders are thought to have had early in their evolutionary history, while the epigastric plates which some species of both families possess may well be surviving relics of segmental plates. Furthermore, reference will be made in section 10 (below) to an unusual use to which pholcid chelicerae are put, a use which may have been customary amongst their earliest ancestors.

The best way of classifying spiders is into two sub-orders, the *Mygalomorphae* and the *Araneomorphae* (*Arachnomorphae*). Some authorities also recognize as distinct sub-orders the *Liphistiomorphae* and the *Hypochilomorphae*, but all agree that the former are linked in relationship to the *Mygalomorphae*, and the latter to the *Araneomorphae*. If, for our purpose, we recognize just two subdivisions of the order, we find that one constant characteristic by which they can be distinguished clearly and easily is the design of the chelicerae. In what may be called the mygalomorph type, the basal segments are directed forwards while the fangs strike downwards in a roughly vertical direction. In the araneomorph type, the basal segment usually slopes downwards, often vertically from the carapace, while the fangs move laterally, inwards towards one another and outwards (figure 2).

Both types arose very early in spider history, certainly by Carboniferous times, so that it is difficult to be sure which came first. The orientation of the chelate chelicerae of other orders provides no clue. It may be noted, however, that the Devonian *Trigonotarbi*, and the uropygids and amblypygids, all have the mygalomorph type. It is probable that the four orders shared a common ancestor, in which spider-like chelicerae of the mygalomorph type arose in or before the Devonian period. Later, during the Carboniferous period, when insects began to develop wings, the araneomorph type arose by some torsion of the basal segment, following a departure from a ground-living habit and the evolution of silk snares where

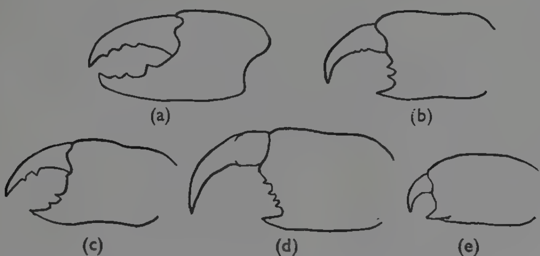


FIGURE 1 – *Chelicerae of* (a) *the scorpions*, (b) *uropygids*, (c) *amblypygids*, (d) *the extinct* Trigonotarbi, *and* (e) *a pholcid spider.*

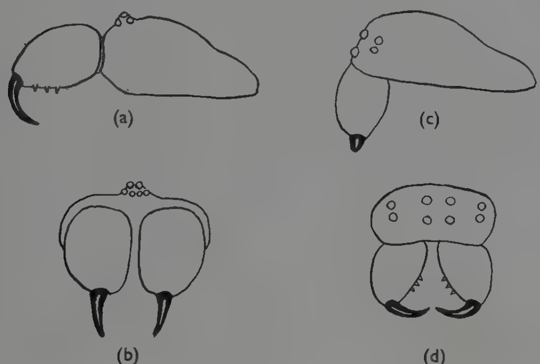


FIGURE 2 – (a) *and* (b) *respectively show the orientation of the chelicerae of the mygalomorph spiders from the side and from the front.* (c) *and* (d) *show the orientation in the araneomorph spiders.*

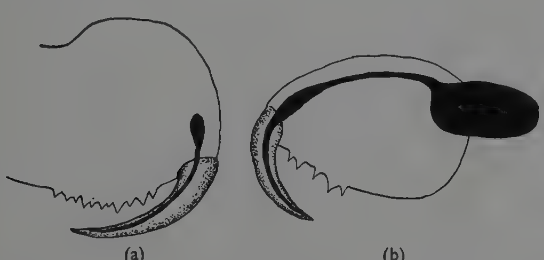


FIGURE 3 – *The poison glands, shown in black, of* (a) *a primitive liphistiid and* (b) *a typical araneomorph spider.*

this design would be more effective for seizing prey. The striking and piercing powers of mygalomorph fangs are greater when the victim is on solid ground than when spider and victim are suspended on elastic threads.

Although the cheliceral design of the uropygids and amblypygids is similar to that of spiders in external appearance, only the spiders possess poison glands. Our most primitive living spiders belong to the family *Liphistiidae*, whose outward appearance closely resembles that of certain Carboniferous fossil spiders. In the genus *Heptathela* there may be no poison glands, and in the genus *Liphistius* they are very small (figure 3) [2, Millot].

The use of chelicerae as weapons of attack and defence is so well known that attention will be restricted to a few features which have been overlooked, or which have received scant attention, before passing on to a brief review of the other interesting uses to which chelicerae are put.

1. SPECIALIZED CAPTURE OF PREY

Observations on five species of *Scytodes* in Malaya and Britain [1] have confirmed the discovery [9, 10] that these spiders squirt gum at insects from a distance of a quarter to half an inch. Under a microscope it is seen that the gum pattern is that of a double series of almost parallel threads which enmesh the insect as if a net had been thrown over it. Although the operation is completed in one jerk, so far as the eye can see, it is evident that the chelicerae are in a state of rapid oscillation at the moment the gum is ejaculated from the fang-tips. Large gum-producing glands are necessary and thus additional space in the cephalothorax is needed, as in the domed cephalothorax so characteristic of *Scytodes* (figure 5).

The dorsal armour of woodlice (*Oniscoidea*) serves as a protection against the bites of most hunting spiders. Furthermore their glandular secretions make them unpalatable to many spiders [3]. Some species of woodlice, however, form a substantial proportion of the diet of the British spider *Dysdera crocata*, a slow-moving nocturnal hunter that lives under stones. Arthropods more active than woodlice can often elude a *Dysdera*, which thus may have been forced to rely largely on woodlice for its diet. Its chelicerae are specially well suited for dealing with woodlice. They are exceptionally large and powerful, and by tilting the cephalothorax sideways one fang is intruded beneath the woodlouse and the other above it. While one fang easily penetrates the soft ventral surface, the other is pressed through the dorsal armour (figure 6).

2. MACERATION OF PREY

The teeth with which the basal segment is armed may serve as some protection for the fang when in repose, but I cannot recall any precise reference to the main purpose they serve. This is to aid in the maceration of soft-bodied prey, so as to facilitate the release of body-juices for the spider to suck. A contraction of the muscles that operate the fangs causes the fangs to press the insect's body against the teeth—to exert a

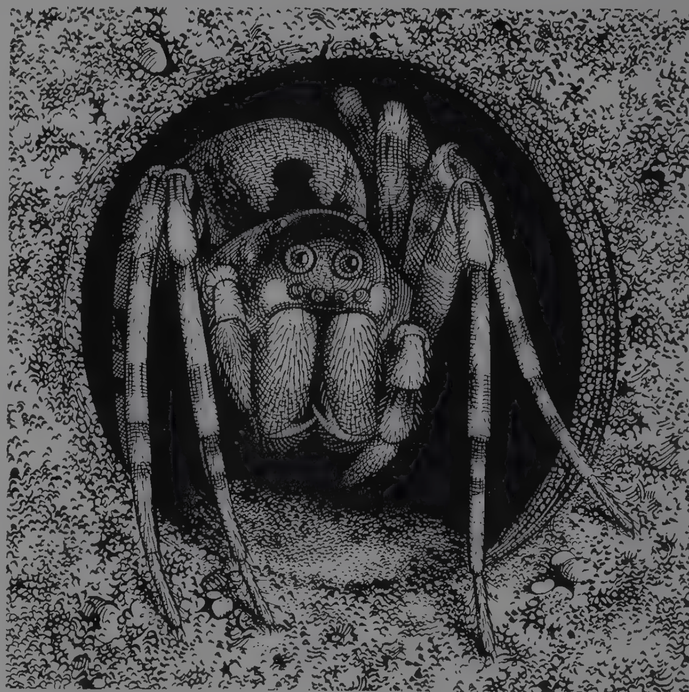
squeeze similar to that of the ancestral pincer. The sharp teeth penetrate the insect's body-wall and help to reduce it to a pulpy pellet. A serrula or series of small teeth on the border of the maxilla also contributes to this process.

3. DISSECTION OF PREY

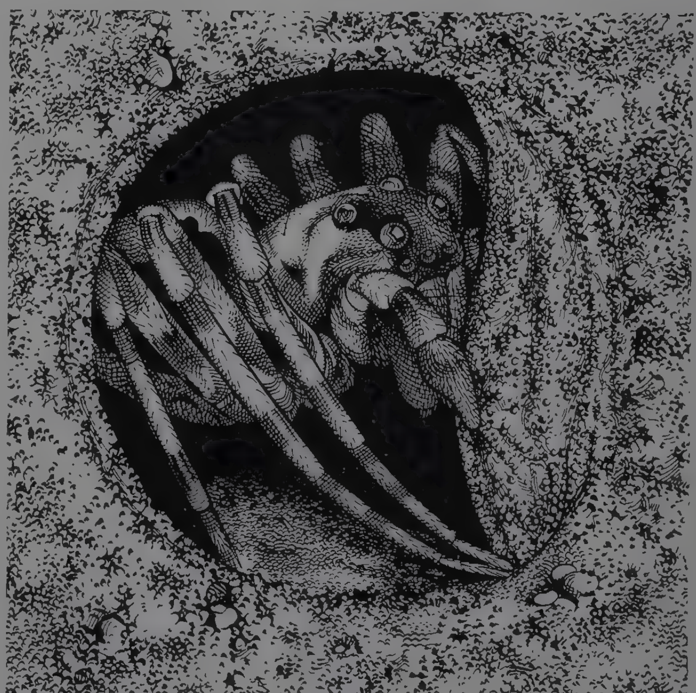
Some families of spiders have no teeth on the basal segments of their chelicerae. These spiders do not macerate their prey or reduce it to pulp. When an insect has been sucked dry through the tiny punctures made by the fangs, it still retains its original appearance and could be appropriately preserved in an insect-cabinet. These spiders usually have small fangs, and it is noticeable that they are adept at finding the chinks in highly armoured insects like weevils (*Curculionidae*), whose armour defeats most other spiders. In a leisurely way the toothless spiders explore the surface, find the joints, and insert their fangs.

The *Theridiidae* provide one example, and it is not without significance that, although these spiders build scaffolding snares, it is often only the basal portions of threads close to the ground or other surface of attachment that are provided with gum. In other words, the snares of many *Theridiidae* are specially designed to capture crawling insects. Now it is more usual for insects which spend all or most of their time on the ground to be armour-plated than for insects which spend most of their time in the air, where the extra weight would be a disadvantage, so an ability to pierce armour is of importance to a theridiid.

The toothless *Thomisidae* can grapple with weevils rejected by lycosids and other hunting spiders. Thomisids, however, often gain a quite different advantage



(a)



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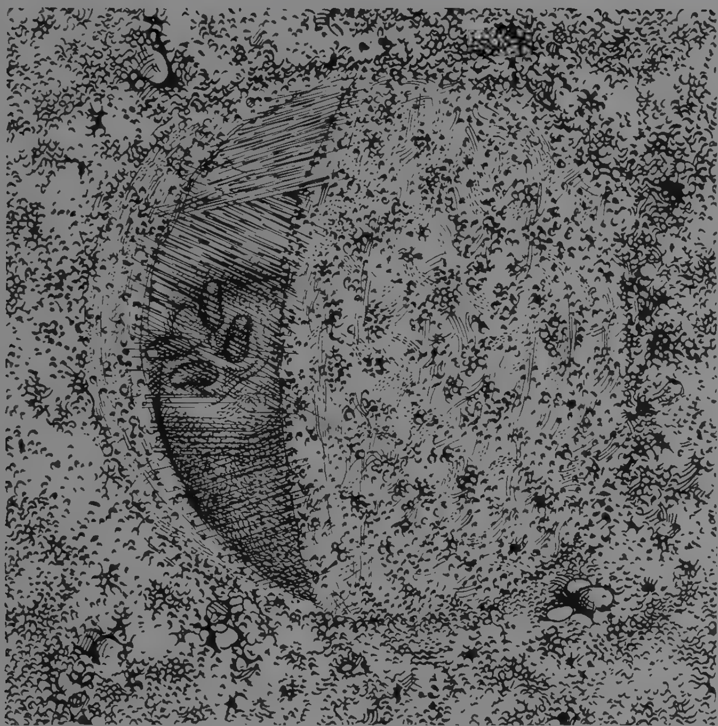

(c)

FIGURE 4 – (a)–(c). Arctosa perita *pulls the silk rim of her burrow across like a curtain when alarmed, and completes the closure with a few sweeps of her spinnerets.*

from not macerating their prey. Several species, including those of the genera *Misumena* and *Thomisus*, lurk in flowers whose colours match those of their bodies. Indeed, within certain limits the spider's colour will change to that of the flower—from yellow to white or *vice versa*—and this makes it inconspicuous to prey and enemy alike. When a visitor to the flower has been caught, the insect continues to look as though it were still alive all the time it is being eaten, and many a naturalist has netted a butterfly or other insect only to find that one of these crab spiders was already making a meal of it. A chewed pellet or a dismembered insect, on the other hand, would draw attention to the spider.

The actual mouth of a spider lies behind the chelicerae. It seems likely that the chitinous ridge or keel which borders the inner side of the basal segment in some spiders helps to control the flow of fluids to or from the mouth. Digestive fluids are pumped into the prey and partially digested liquids are then sucked back into the mouth.

4. BUILDING OPERATIONS

The spiders of several families excavate tunnels in the ground; the chelicerae are used to loosen and carry the earth to the surface. The British *Atypus* pushes the earth brought from underground through a closed silken tube which extends two or three inches above the ground, and then, with her long fangs protruding through the tube wall, lines the outside with grains of earth. This delicate operation performed by the fangs helps to camouflage the external portion of the tube.

Relations of *Atypus* that live in climates warmer than that of Britain often close their burrows with beautiful hinged trap-doors. The shaping of these doors is carried out by the fangs. A species in Majorca forms a series of notches along the edge of the circular door which fit exactly into grooves round the burrow's rim, and I have watched the spider (*Nemesia* sp) shaping each notch and groove with its fangs. Some of these trap-door spiders have developed a rastellum or rake at the apex of the basal segment of their chelicerae, which is used in the excavation of burrows. With it they scrape and dislodge the earth (figure 7).

A British lycosid, *Arctosa perita* Latr., excavates a burrow in sand and lines it with silk. When she is alarmed, I have seen her seize the rim with her chelicerae and pull it across like a curtain. Then she rapidly turns round and with a few sweeping zig-zag strokes of her spinnerets closes the last chink (figure 4).

The chelicerae are used in various ways in the construction of the silken egg-sacs or cocoons. They help to shape some egg-sacs, to incorporate more or less mud as a strengthener, to plaster mud on the outside (as in the British *Agroeca*), and even to give that waterproof polished effect characteristic of the genus *Zelotes*. E. Nielsen [11] has described how a *Zelotes* holds grains of earth, moistened with saliva, in her chelicerae and rapidly rubs these over the surface backwards and forwards from the centre of the egg-sac to the circumference.

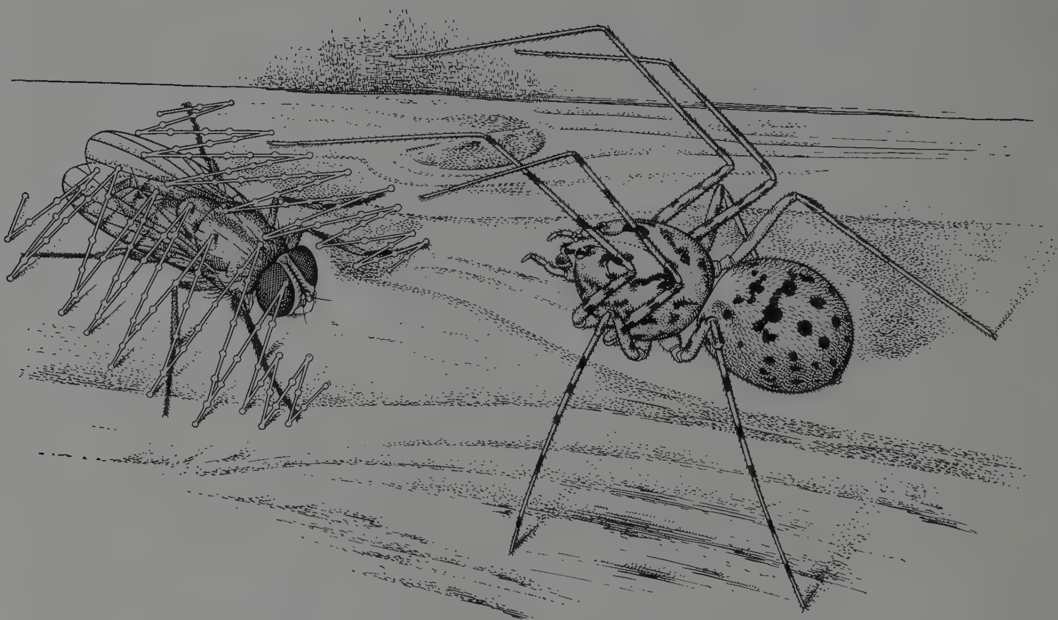

FIGURE 5 – Scytodes *captures insects by squirting gum from her chelicerae.*

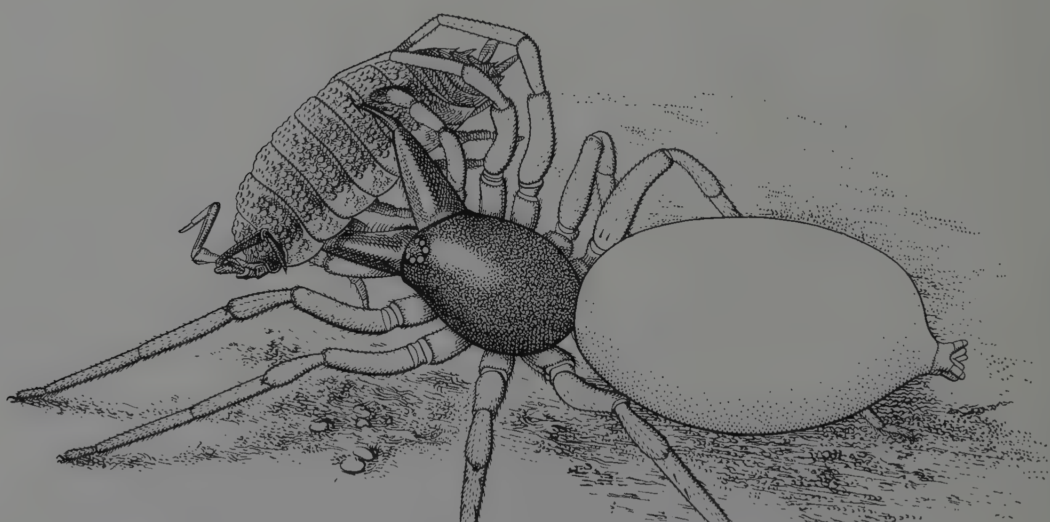

FIGURE 6 – Dysdera's *large fangs are well suited for gripping woodlice and piercing their armour.*

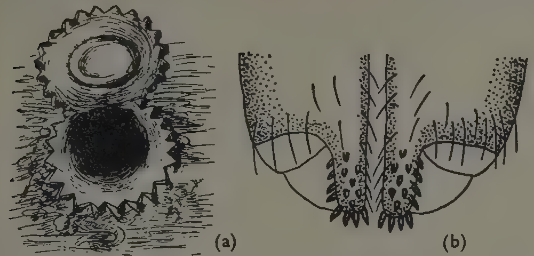

FIGURE 7 – (a) *The notched trapdoor of an undescribed* Nemesia *from Majorca;* (b) *rastellum on basal segment of the chelicerae of* Actinopus (*after J. Millot*).

5. A TOOL FOR CUTTING

The chelicerae are used for tearing and cutting the spider's own threads when destroying an old snare before building a new one, or in the tidying of a new one, as for instance in the construction of the open-ring centre characteristic of the orb webs of *Tetragnatha* and *Meta*. The need to cut threads or web occurs also on other occasions, which cannot all be enumerated. Instances, however, include the occasional cutting of a hole in a sheet web as the quickest means of chasing an insect struggling on the wrong side of it (*Tegenaria*), and the cutting of an exit hole in a closed silken cell in which the spider has been resting. The fang plays a large part in operations of this kind, but the importance of the teeth seems to have been overlooked.

In *Atypus* this is specially interesting. *Atypus* lives in a closed silken tube and transfixes insects with its long fangs through the tube wall. That careful observer, F. Enock, described [4, 5] how the spider then clenches the insect against the tube and presently, after some tugging, pulls it through a neat hole in the tube wall, but he did not wrest from the spider the method by which this hole is made. Inspection of the teeth on the basal segment, however, will reveal the effect of the clenching action. Two weak lines in the silken fabric are made, each with eleven or twelve closely spaced perforations where the teeth have pierced the tube wall. A heave, and the perforations are joined, leaving two slits which lead to the two large holes made by the wide bases of the fangs. Further tugging and sawing complete the cutting of a flap in the tube wall, leaving an aperture through which the prey can be hauled.

This unique saw-like arrangement of the teeth is found in all the *Atypidae*, and is clearly an adaptation associated with their closed-tube method of capturing their prey (figure 8).

6. CLEANING THE LEGS

It is a common sight to see a spider passing the tarsi and metatarsi of its legs through the chelicerae, during which action the chelicerae are in movement as though they were chewing. No doubt this cleans the legs, and also re-moistens them with fluid from the mouth. The thick brush of bristles with which most basal segments are furnished plays a part in this operation.

7. STRIDULATION

Stridulating apparatus has been evolved independently in several different families of spider. In some families the apparatus is associated with the chelicerae; in others it is situated between the cephalothorax and abdomen.

Sometimes stridulatory organs are present in both sexes, and are used to alarm an enemy when the spider is threatened. In other cases the organs are often present only in the male, who can be seen using them during courtship. It does not necessarily follow that the female can hear any sound—in all probability she cannot—but the rubbing of teeth against a file, for instance, will set up distinctive vibrations which pass along the threads of her snare.

Mygalomorph spiders come in the former category; the *Linyphiidae* and other web-builders are in

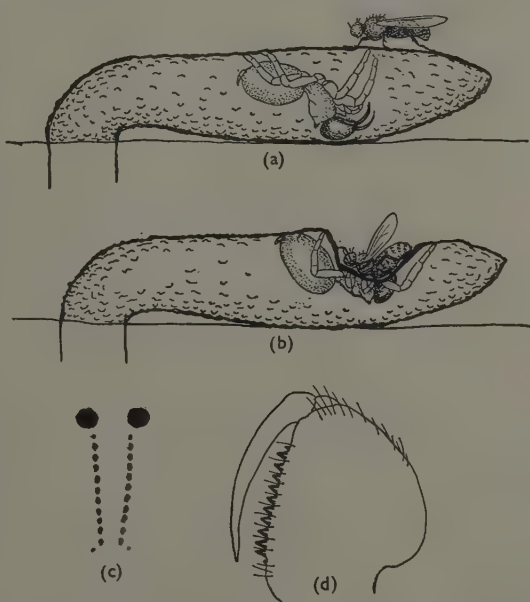

FIGURE 8 – (a) Atypus *about to strike an insect through the wall of her closed silk tube;* (b) *pulling and squeezing the insect against the wall. This action causes two lines of perforations* (c) *in the wall owing to the arrangement of teeth on the basal segment* (d). *Heaving, and aid from a fang, soon convert the perforations into a slit, through which the insect is pulled.*

FIGURE 9 – *A bloodless struggle between two males of* Salticus scenicus *Linn. in which the large chelicerae are spread out laterally.*

the latter. The detailed structure of the stridulatory organs varies considerably in different families, but, where the chelicerae are involved, the outer border of the basal segment bears either a file or spines of special design, which produce sound or vibrations not audible to human ears when rubbed against a tooth or special spines on the palpal femur.

8. COURTSHIP

Displays by the males are usual amongst the long-sighted hunting spiders (*Salticidae*, *Lycosidae*). The males have evolved many forms of decoration which, combined with the displays, serve to advertise their identity to their more powerful females. A continuation of the display leads to the female's submission when the sexual instincts dominate the preying instincts [3]. The decorations include enlarged leg segments, contrasting colours or tones, and tufts of hair, which, whatever they may be or wherever situated, are carefully displayed to the female. Some male salticids have greatly enlarged chelicerae. They are less efficient than normal-sized chelicerae, but in the British *Salticus scenicus* Linn. they are the only decoration not possessed by the female. During the courtship display, and during bloodless struggles between two males (figure 9), the basal segments are stretched somewhat outwards. In this position they become conspicuous to the female whom the male is facing.

9. HOLDING THE FEMALE DURING MATING

It is typical of the short-sighted male thomisids that once they find a female they do not risk losing her. Displays amongst short-sighted spiders would serve no purpose, so he boldly seizes the femur of one of her front legs and holds on until her struggles cease. No damage is done to the female's leg, perhaps because the thomisid males have no cheliceral teeth.

In the *Agelenidae* the females submit to the males and lie still after an interplay of legs. Often an agelenid male will grip a female's leg and drag her to a position suitable for mating. In some spiders the male's chelicerae are specially adapted for holding the female's chelicerae to avoid being bitten. Some species of *Dictyna* have 'bow-legged' basal segments. The female's chelicerae fit into the space so produced and are held closed.

The males of *Tetragnatha* all have a stout chitinous spur or tooth projecting outwards from their cheliceral basal segments. When the sexes come together the female opens her chelicerae as though to bite the male, and he wedges them wide open with these spurs. They mate in this position. *Pachygnatha* is a relation of *Tetragnatha* which has forsaken web-building and taken to a wandering existence. He too holds the female's fangs during copulation, but in a different manner. In the middle of each long fang is a projection on the inner side, and opposing this is a large tooth on the basal segment. When these come together a small space is left near the base of the fang. The female's fangs are imprisoned in these spaces like human wrists in a pair of handcuffs (figure 10).

10. OTHER HOLDING USES

The chelicerae fulfil many holding functions, and I shall not try to list them all. They hold the

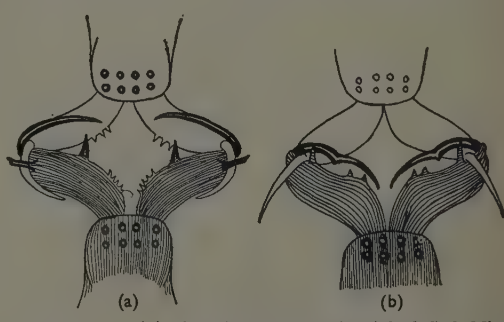

FIGURE 10 – (a) *A male* Tetragnatha (*shaded*) *holding open the fangs of the female with special teeth on the basal segment;* (b) *a male* Pachygnatha *handcuffing the female's fangs.*

prey, for instance, and neat punctures inside the doors of trap-door spiders show how these are held shut with the fangs (figure 7). Some spiders, including *Pholcus*, hold their egg-sacs in their chelicerae until the young hatch.

Spiders are not the only arachnids to ejaculate sperm and then, as a separate process, to transfer it to the female's body. The *Solifugae* and certain *Acarinae* which have chelate chelicerae make the transfer of the sperm with them. In spiders, the sperm is transferred by the palps. The pholcids are unique amongst spiders in holding the ejaculated sperm in their chelicerae and absorbing it thence into their palpi. In other spiders the sperm is ejaculated on to a small web, where the palps are dipped into it. May not the pholcid's chelate chelicerae, the habit, and the simple sexual organs, all be significant primitive survivals, as I suggested earlier when tracing the evolution of spiders' chelicerae?

II. UNEXPLAINED ABNORMALITIES IN THE CHELICERAE

In this survey of the uses to which chelicerae are put it is remarkable how often an unusual tooth, spur, spine, or other abnormality has been found to serve some purpose for which it has been adapted. There are, however, some cases of abnormal size in the male sex which appear to serve no useful purpose at all. Why, for instance, are the chelicerae of the males of *Linyphia triangularis* Clerck and *Theridion ovatum* Clerck larger than those of their females? All we know is that the male spiders themselves are subject to marked variations in size, and that the chelicerae of large specimens are relatively larger than those of small specimens. G. H. Locket [7, 8] has examined this allometric growth of the chelicerae mathematically in several species, and believes it to be of frequent occurrence in spiders—as I do myself from general observation. It certainly applies, for instance, in such salticid genera as *Myrmarachne*, where the size of the male chelicerae in large specimens is almost fantastic.

It should also be mentioned that the chelicerae bear lyriform organs and a variety of different types of hair, bristle, and spine, some of which undoubtedly are sensory but whose precise function is not yet clearly understood.

SUMMARY

Ancestral arachnids had chelate chelicerae. In or before the Devonian period the immovable finger of the chelae diminished in size in some arachnids, and became a large tooth, leaving the movable finger as a fang (as in the extinct Devonian *Trigonotarbi* and the surviving orders of uropyges, amblypyges, and *Araneae*). The large tooth on the basal segment of pholcid spiders is thought to be homologous with the immovable finger of the chelae of ancestral arachnids. Very early in the history of the *Araneae*, by Carboniferous times or earlier, two types of chelicera had been developed like those found today in the sub-orders *Mygalomorphae* and *Araneomorphae* respectively. It seems probable that the latter arose from the former type by a torsion of the basal segment.

The chelicerae are used not only in attack and defence but also for macerating and dissecting prey, as tools for building operations, for cutting web, cleaning legs, stridulation, courtship, holding the female and egg-sacs, and for other purposes. In several cases the structure has become suitably modified. Attention is called to the special functions of the teeth situated on the basal segment in macerating prey, and in cutting a hole in the tube-wall of *Atypus*, and also to the manner in which *Arctosa perita* closes her burrow entrance with the help of her chelicerae.

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Book reviews

SOLVENT TOXICITY

Toxicity of Industrial Organic Solvents, *by Ethel Browning. Revised edition. Pp.* 411. *Her Majesty's Stationery Office, London.* 1953. 35*s. net.*

The first edition of this book (1937) is well remembered by workers in many fields, including those in industry, and brought home to many the potential dangers of solvents. This edition went rapidly out of print, to the regret of those who were unable to purchase it, and sixteen years elapsed before the edition under review appeared. A first reaction is a criticism of the length of time which has gone by—too long for a work of this importance—but on perusing the pages one is impressed by the great amount of work which the author has accomplished and the vast literature which has been examined and listed. Space does not permit of full justice being done to the book here, but it is clearly one which should be in the hands of those responsible for industrial health, and be available to all those in control of factories using solvents.

Each monograph aims at giving the essential physical constants; the uses; the toxicity, acute and chronic, to man and animals; the allowable concentration in air and in many cases its determination; and the pathological effects upon the tissues of the body.

The reviewer feels that the work should be a very valuable guide in controlling factory conditions, so that the earliest toxic effects may be noted before the onset of serious illness and possibly death. To those who wish to study in detail the toxicity of any particular solvent it may be noted that there are over 42 pages of references, containing more than 1500 names.

In conclusion, an especial word of thanks and congratulations must be extended to the author.

G. ROCHE LYNCH

HOW FUNGI SPREAD

Dispersal in Fungi, *by C. T. Ingold. Pp.* 197, *with half-tone and line illustrations. Clarendon Press, Oxford.* 1953. 18*s. net.*

In Professor Ingold's earlier book, 'Spore Discharge in Land Plants' (1939), approximately half the text dealt with the fungi. This portion has now been revised and extended, to provide a comprehensive survey of the dispersal of fungus spores.

An 80-page chapter on spore liberation gives detailed accounts of the orientation of spore-releasing surfaces and of the functioning of the diverse structures responsible for spore discharge. The emphasis is on the mechanisms of ascospore ejection, but the chapter includes descriptions of the 'water rockets' of *Basidiobolus*, the 'catapult' of *Sphaerobolus*, and other more conventional types of spore release found in the *Phycomycetes* and *Basidiomycetes*.

The account of the further dispersal of the liberated spores is continued under the headings of spore distribution in the air; dispersal by insects and by larger animals; seed-borne fungi; and dispersal by water. This last chapter gives a brief but fascinating glimpse into the author's recent work on the aquatic fungi. There is an up-to-date bibliography of 142 titles.

The text is admirably partnered by eight plates and ninety line figures, most of which are original. These have the animation appropriate to the subject and reflect something of the enthusiasm with which Ingold's book is inspired.

R. W. MARSH

ONE VIEW OF SOIL RESTORATION

Soil Restoration, *by Edward Faulkner. Pp.* 208. *Michael Joseph, London.* 1953. 10*s.* 6*d. net.*

In his final chapter the author writes: 'To many a reader I shall seem to be a cultist of the worst order. Naturally to myself I seem anything but that. Perhaps it is somewhere between that the truth lies.' Most of the book falls definitely within the cultist category. Mr Faulkner gives a somewhat rambling account of what he terms the restoration of a small patch of land, but he has certainly taken the long and hard way regardless of cost, and we are asked to believe that the effort was justified by the freedom of the crops from diseases and pests and the quality of the produce. Most of the theories he propounds are far from original and there is good scientific evidence to show that some of them are thoroughly unsound. Long before Mr Faulkner wrote 'Ploughman's Folly' it was well known that, under certain circumstances, other forms of cultivation are better than ploughing, but practical experience and careful experimentation have shown that, in general, the plough performs a very useful function. The value of composts is well understood, but surely it is not seriously suggested that food production could be maintained at present levels with crop residues and composts supplemented by underground water 'loaded with minerals of every kind'? There is too much fancy in this book and too little fact.

W. G. OGG

LIFE OF KEPLER

Johannes Kepler: Life and Letters, *by Carola Baumgardt, with an introduction by Albert Einstein. Pp.* 209. *Victor Gollancz Limited, London.* 1952. 12*s.* 6*d. net.*

This interesting book is essentially a short biography of Kepler, which includes the first translations into English of a selection of his letters. This feature greatly enhances its value. The author leaves to Einstein the assessment of Kepler's scientific work, which is made in a short introduction, while she herself is primarily concerned with presenting to her readers Kepler the man, as revealed in his struggles against the difficult circumstances of his life and times, and in his correspondence.

Prematurely born, always in frail health, his sight severely impaired through smallpox, inadequately paid and sometimes not paid at all in the various posts that he occupied, maintaining himself when necessary by calendars and prognostications, a liberal Protestant when all tolerance was suspect, and moreover a follower of the heretical Copernican theory, discoverer of the laws of planetary motion that have since immortalized his name but which had little interest for his own age, his last years harrowed by the charge of witchcraft brought against his mother: such were Kepler's trials, yet, as these letters show, he never lost his lightheartedness, his sensitivity of mind, his belief in God as the source of the spiritual and physical laws of the universe.

A well written book which, for English readers, sheds much light on Kepler's personality.

D. MCKIE

CHRISTIANITY AND SCIENCE

Christianity in an Age of Science (Riddell Memorial Lectures), *by C. A. Coulson. Pp.* 53. *Oxford University Press, London.* 1953. 5*s. net.*

Professor Coulson asks what status should be granted to religion in an age of science: and answers the question by considering the way in which a man of science approaches the whole question of reality and truth, showing that it provides a natural approach also to religion. To the man of science, his experiences are primary, and his scientific constructions (electrons, genes, and so on) are introduced in order to relate the experiences together into a satisfying and orderly scheme. There are, however, patterns other than the scientific, equally good at co-ordinating experiences. Thus when a man says 'The concept of a personal God enables me to relate together many of my most profound experiences,' his attitude is essentially the same as that of the man of science. The process by which we attain a belief in God is of the same character as the process by which we attain a belief in the existence of the minds of our fellow-men. From these beginnings, the author develops a view of the coherence of all reality, with God as the integrating principle within whose being scientific laws, artistic efforts, and personal religious experiences are different facets of one whole.

EDMUND WHITTAKER

MIND AND BRAIN

The Neurophysiological Basis of Mind, *by J. C. Eccles. Pp.* 314, *with line illustrations. Oxford University Press, London.* 1953. 25*s. net.*

This book, reproducing eight lectures which Professor Eccles delivered in the Hilary Term of 1952 in Magdalen College, Oxford, is really an astonishing achievement. His aim, as the main title indicates, was to find some clue to the missing link between the activities of the brain, as these are now being progressively analysed with all the refinements of the most advanced physiological technique, and those activities which we attribute to the mind, and of which our knowledge seems to us the most direct, and independent of any sensory mediation. Evidence accumulates ever more rapidly of the intimate dependence of these mental processes on the functional integrity of the brain, with its fantastically complicated traffic of excitation and inhibition across its almost inconceivably numerous synapses. The meaning of this intimate relation between sequences of events which seem to be essentially disparate may be regarded, by physiologist and philosopher alike, as the ultimate mystery to be explored; but, hitherto, the greatest followers of either discipline have seen no prospect of finding a clue to it. Some might be content to doubt whether man's conscious mind will ever be able to unravel the almost infinitely complex chain of material happenings in the brain, on which the mind's activities somehow and so intimately depend, and thus to escape from the illusions of spontaneity, volition, and free will. Watching movements of an amoeba, we find it difficult not to regard some of them as 'voluntary,' though we do not hesitate to give them a material, deterministic interpretation. We ourselves cannot unravel even this chain, and we certainly do not expect the amoeba to do so.

Eccles is not disposed, however, to recoil from the mystery, as thus intangible. On the contrary, he prepares his Magdalen audience for an attempt to solve it, by laying a most elaborate groundwork of the latest physiological analysis of the activities of the whole nervous system, including a description in outline of the relevant features of its anatomy. For such a presumably mixed audience, the chapters representing these seven lectures, and leading up to the essential problem in the eighth, might be regarded by some as overloaded with detail. A physiologist, on the other hand, may applaud them as a *tour de force*, and admire, by the way, Eccles' skill as a leading advocate now, in chapters III and IV in particular, of a conception to which, until his recent and sudden conversion, he offered a stubborn and stimulating resistance. With sympathy for the shorn lambs among his readers, he himself suggests, in his preface, some very extensive skippings in these specially physiological chapters, to come the more rapidly, in chapter VIII, to the heart of his chosen problem.

Can the reader expect to be satisfied that Eccles has come nearer than any of his distinguished predecessors to a solution of this problem—to the discovery of an intelligible link between orders of experience apparently so incompatible? Honestly, it has to be doubted. 'The neurophysiological hypothesis,' he writes (p. 277), 'is that the "will" modifies the spatio-temporal activity of the neuronal network by exerting spatio-temporal "fields of influence" that become effective through this unique detector function of the active cerebral cortex.' One feels bound to suspect that the mind of the reader would have to be rather deeply benumbed and bemused by the luxuriance of technical expositions in earlier chapters before he could begin to feel satisfied by this. Eccles does not shrink, however, from what seems to be the simple meaning of such an impressive pronouncement. What we know as mind is clearly somehow dependent on material happenings which we record with increasing precision of detail in the brain; to understand how it is so, we have only to suppose, it appears, that the mind can exercise spatio-temporal 'fields of influence' (whatever that may mean) on material events; and, as evidence of the admissibility of such an assumption, Eccles cites the now well known statistical claims for a 'psychokinetic' influence of mind on the fall of dice, etc.

Convincing? Not to the reviewer, by a long way. But nobody interested in such problems can afford to miss Eccles's masterly assembly of physiological data, or can fail to admire his courage and his independence of tradition.

H. H. DALE

A CHEMICAL ENCYCLOPAEDIA

Encyclopedia of Chemical Reactions, *compiled and edited by C. A. Jacobson with the assistance of C. A. Hampel and E. C. Weaver. Vol.* 5. *Pp.* 787. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 120*s. net.*

The present volume of the series deals with the elements nickel to ruthenium in alphabetical order. The text consists of statements of the reactions, accompanied by chemical equations and references to the sources in each case. In the case of nickel carbonate, for example, the formula $NiCO_3$ is repeated as heading, and below is the symbol of the reactant in each entry. In some cases, details of the way the reaction is carried out are given. There are indexes of reagents and of substances obtained. The volume has been compiled from the literature by 118 abstractors. The book is well printed on good paper and strongly bound, so that it should withstand laboratory use.

Many of the reactions are well known, but in general the reference is to the latest publication dealing with a specific reaction, so that in this way it is possible to infer that a statement in an old source has been checked. In some cases the information, although brief, is detailed enough to serve as a guide to a preparation. In other cases

the reactions are of interest in chemical analysis, when the procedure to be used in the test is stated.

It should be obvious that the work is not intended to replace the existing treatises on inorganic chemistry, but to provide in a compact form a body of information which may be required at short notice in a laboratory, and it would seem to fulfil its object very well. Every reader will find matters of detail which can be criticized, but on the whole the series of volumes is likely to serve a useful purpose. If they are available in a laboratory their use may save a good deal of time which would otherwise be spent in searching through more bulky literature. The reviewer found a large number of reactions listed which were unknown to him, and the existence of which he would not have suspected, and the scope of the book is wide enough to make it appeal to the specialist. Jacobson did not live to see the completion of his work, but the other two editors promise to carry on the series. The reviewer thinks this is a useful book which should be available in every chemical laboratory.

J. R. PARTINGTON

STARCH

Starch and its Derivatives, *by J. A. Radley. Vol. 1 (3rd edition). Pp.* 510, *with half-tone and line illustrations. Chapman and Hall Limited, London.* 1953. 65*s. net.*

This volume constitutes a genuine revision of the second (1943) edition, and a large amount of new material has had to be surveyed. The author has been assisted by nine well known carbohydrate chemists, and the book is therefore authoritative. There are a chapter by S. Peat on the biological function of starch, and an excellent synopsis, by L. Hough and J. K. N. Jones, of the chemical evidence for the structures of the components of starch.

Particularly interesting is the collaboration of American chemists, who deal with the starch fractions, the waxy cereals and starches which stain red with iodine, dextrins and dextrinization, and the esters and ethers of starch, these latter contributions being by E. F. Degering.

Later chapters are concerned with amylases. After discussing the general problem, Radley describes the preparation of enzymes used in the starch industry, and the action of α- and β-amylases on starch.

The various approaches to the starch problem are followed, so that the present volume will be attractive to both academic and industrial chemists. References to the literature are copious, though carefully selected. In spite of its divided authorship the book has a pleasant coherence. The volume is unusually free from typographical errors, but the uncritical use of the words 'corn' and 'maize' is a little irritating. In the editorial preface there is some rather unsound dogma about the value of scientific papers.

E. E. TURNER

ROTATING LIQUID MASSES

The Stability of Rotating Liquid Masses, *by R. A. Lyttleton. Pp.* 151, *with line illustrations. Cambridge University Press, London.* 1953. 35*s. net.*

In 1687 Newton explained precession as due to the attraction of the Sun and Moon on the equatorial protuberance of the Earth, regarded as an oblate spheroid, and half a century afterwards Maclaurin showed that the oblate spheroid is a possible figure of equilibrium for a rotating fluid mass. The subject thus opened up has been greatly developed in the last two hundred years. Jacobi showed that an ellipsoid with three unequal axes is also a possible form of equilibrium, and Sir George Darwin studied what he called the 'pear-shaped' figures, while Poincaré, followed especially by Jeans, examined the stability of the known forms. These investigations seemed to indicate that a rotating liquid might ultimately divide into two detached portions in orbital motion about each other, and an explanation might thus be provided for the origin of binary stars—a theory that was expounded in Jeans's books on cosmogony of 1919 and 1929.

Lyttleton concerns himself mainly with this problem of the evolution of gravitating liquid masses, and his principal achievement is to show that the dynamical evidence is against the fission process. The last chapter contains an interesting discussion of some views on the origin of the planets and satellites.

EDMUND WHITTAKER

EPIGENETICS

The Epigenetics of Birds, *by C. H. Waddington. Pp.* 272, *with line illustrations. Cambridge University Press, London.* 1952. 35*s. net.*

The study of heredity has proved that the development of the fertilized egg is determined by what is inside it. The study of this determination, its analysis into separate processes, is what Waddington describes as 'epigenetics.' Its beginning requires us to recognize the division between nucleus and cytoplasm within the cell, the localization of materials, their limited and variable diffusion, and the consequent chemical gradients within and between cells. Its further developments require us to note the genetic character of cell-lineages and of infectious particles both in normal development and in the growth of tumours. Its present controversies deal with the immunological character of tissues, with the reactions of fixed cell-constituents and diffusing hormones, and with the imitation of genetic effects by timed experimental treatments.

These notions give an inductive unity to the study of development in all animals and even, to some extent, in plants. But so diverse are the materials and so variously co-ordinated are the processes, that there is probably room for detailed descriptive reviews of small aspects of the techniques and limited sections of the literature. This is the line the author has followed in confining himself to birds, and more particularly to recent work on the manipulation of the chick embryo. This field, however, has proved to be theoretically one of the least rewarding in embryology. The result is, therefore, although most conscientiously prepared, none the less inevitably diffident and even depressing. It makes one ask whether the term epigenetics, with its suggestion of fundamental genetic principles, is not premature and somewhat misleading. One certainly ends with the uncomfortable feeling that this term alone is not enough, with the best will in the world, to induce or evoke or organize a science.

C. D. DARLINGTON

THE U.S. PACIFIC COAST

Between Pacific Tides, *by E. F. Ricketts and J. Calvin. (Third edition, revised by Joel W. Hedgpeth.) Pp. xiv* + 502, *with* 134 *text figures and numerous plates. Stanford University Press, California; Geoffrey Cumberlege, London.* 1953. 48*s. net.*

It is a pleasure to review this book, which has become a unique feature in the history of biological publications. It is the first popular book to have described the intertidal zonation along a whole coastline as long as that of the Pacific coast of the United States, and the distribution and natural history of the animals in relation to this. It has

had a well deserved success since its first edition appeared in 1939, and although popular in form is indispensable to professional biologists and students. The principal author, E. F. Ricketts, suffered an untimely death in a motor-accident. As he was an unconventional naturalist of genius, and a character of unusual distinction, his loss is a serious one. It is a little mitigated by the fact that in the new edition, edited by Joel Hedgpeth, we are presented with personal details about Ricketts which will have been unknown to many of his readers. Dr Hedgpeth has edited the work very capably, and has added welcome sections on seaweeds and on the general question of intertidal zonation.

T. A. STEPHENSON

LIFE OF BUFFON

Buffon, *by L. Bertin, F. Bourdier, E. Dechambre, Y. François, E. Genet-Varcin, G. Heilbrun, R. Heim, J. Pelseneer, and J. Piveteau. Edited by R. Heim. Pp.* 246, *with half-tone illustrations. Publications Françaises, Paris.* 1952. *Fcs.* 900 *net.*

Buffon's complex and remarkable personality could be truly depicted only by a collection of qualified specialists. F. Bourdier deals with the main aspects of Buffon's life and work. In a chapter full of surprises, L. Bertin discusses the manifold activities of Buffon as man of affairs. Y. François's chapter is entitled 'Buffon and the royal gardens'; he outlines Buffon's tremendous task in raising the gardens to the status of a first-rate scientific establishment, a task which represents one of the great naturalist's principal claims to remembrance. J. Piveteau analyses Buffon's religious notions and his successive attacks on the problems of materialism and spirituality. J. Pelseneer deals with Buffon as metaphysician in discussing an unpublished letter to Guyton de Morveau on the phlogiston theory. Mme Genet-Varcin paints a brief picture of Buffon's ideas on the generation of living creatures. E. Dechambre takes as his subject the article on dogs in the *Histoire Naturelle*, and brings before us the great experimenter and forerunner of modern biologists. Finally, the man himself is revealed in F. Bourdier's chapter on the portraits of Buffon, which also contains a number of unpublished letters. The bibliography of Buffon's publications drawn up by G. Heilbrun shows us the gradual unfolding of this great body of thought.

To unify this collection, some kind of general summary is required. This is provided by R. Heim's preface, in which he brings together the essentials of the rest of the book in a masterly synthesis of the man and his work, his ideas, and his philosophy of life. From this admirably produced volume there emerges the figure of Buffon, hitherto all too little known, yet one who has contributed in no small degree to our knowledge of the world and its mysteries.

MAX VACHON

WOOD CHEMISTRY

Wood Chemistry, *edited by L. E. Wise and E. C. Jahn. Second edition. Pp.* 1277 + *indexes, with half-tone and line illustrations. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1952. *In two volumes,* 120*s. net each.*

A knowledge of the relevant basic chemistry is becoming increasingly important to all concerned with the utilization of wood, whether as a raw material for chemical industry or for constructional purposes. Soon after its appearance in 1944, the American Chemical Society's Monograph No. 97, 'Wood Chemistry,' became recognized as the standard work on this subject. Developments in recent years have been so rapid that in preparing a second edition of this monograph it has been found necessary to expand it into two volumes.

The whole work has been carefully revised, and many of the chapters, each of which is written by a specialist, have been considerably enlarged, or completely rewritten under new authorship, in order to bring them up to date. New chapters have been added on some aspects of the subject. The fundamental chemistry of wood is dealt with in volume I, which includes a comprehensive treatment of the chemistry of the major components (cellulose, the hemicelluloses, and lignin) and the minor components of wood. The latter section provides a valuable and unique account of the wide range of types of organic compounds found among the extraneous components of wood.

In volume II the applied aspects of the subject are fully discussed. These include not only the different branches of industrial wood chemistry, but the surface properties of cellulosic materials, the decomposition of wood by micro-organisms, and the chemical analysis of wood. While the many valuable features of the earlier edition are retained and in many cases improved upon, perhaps the outstanding new contributions are a chapter by H. Erdtman on the relationship between the extraneous components of the heart-wood of conifers and their taxonomy, and a masterly review by W. G. Campbell of the biological decomposition of wood, containing much material not previously assembled in one article.

The production is of a high standard and the monograph is very fully documented. It is provided with a subject index, but there is no author index.

R. H. FARMER

PLANT GEOGRAPHY

Manual of Phytogeography, *by Léon Croizat. Pp. viii* + 587, *with* 105 *plant-distribution maps and one figure. Dr W. Junk, The Hague.* 1952. *Fl.* 45; 90*s. net.*

In a comprehensive work on plant geography a reasonable expectation would be to find a statement of basic principles and working methods, and indications of the new conceptions and interpretations, set forth in such a manner as to be of interest not only to the specialist but to the general reader, for an essential feature of this branch of botany is that it is of general interest and lies well within the general comprehension. Let it be said at once that these expectations are fulfilled in this very lively and interesting book. The author has approached his subject with a wide knowledge of taxonomy and general botany, and a keen interest and curiosity regarding the distribution of plants in space and time—phenomena that are certainly among the most enigmatic and thought-provoking with which the botanist has to deal. The author has a strong conviction regarding his conclusions, and he does not hesitate to express disagreement with the views of others.

The means of plant dispersal by the various agencies are almost certainly not as simple as has been supposed; indeed, some species have no very evident means of dispersal, yet they have become widely distributed, and are, in fact, self-dispersing from centres of origin. It was essentially this kind of problem that engaged the author's interest, and he has attempted to provide scientific explanations by the scrutiny of the relevant data for hundreds of different groups and families. The results of this monumental undertaking are set out in over three hundred pages of taxonomic and geographical

data, illustrated by many charts. The author is well aware how large is this task and how numerous are the pitfalls, and he has duly safeguarded his position; but he has undoubtedly made a significantly constructive contribution to his major theme of 'presenting a global picture of plant dispersal in space and time.' The basic data are the records of plant distribution and taxonomic relationships; from these, important generalizations regarding plant migration can be drawn. Croizat's approach is simple, but it leads to imaginative and far-reaching reconstructions, the validity or non-validity of which will become evident with the passage of time and the pursuit of further investigations. In this work the concept of genorheitron has a central place, i.e. that 'streams of plant life, laden with evolutive potential,' yield varieties, species, and genera at points along the track of dispersal, the whole constituting an orderly biological process. In the author's view, phytogeography is concerned not only with the interpretation of plant dispersal, but with how plants evolve during that process.

Briefly, the author concludes that the great contemporary angiosperm flora originated in the pre-Cretaceous continent of Gondwana (which occupied practically the whole of the modern Indian Ocean), and that access was thence afforded to each of the great continental masses of today. Plant migrations are held to be 'orderly, precise and repetitious,' having taken place from centres of dispersal in the former unified southern continental mass. Whether the author's major conclusions are right or wrong is a matter which only the future can decide, but meanwhile this vigorous and imaginative book can be recommended as a clear and, indeed, entertaining statement of the essential problems.

C. W. WARDLAW

'WORLD LIST'

World List of Scientific Periodicals Published in the Years 1900–1950, *edited by W. A. Smith and F. L. Kent, assisted by G. B. Stratton. (Third edition.) Pp.* 1058. *Butterworths Scientific Publications, London.* 1952. 12 *guineas net.*

This edition of the 'World List' contains the titles of some 14 000 more periodicals than did the second edition of 1934. The war period of 1939–45 saw the temporary eclipse of many old-established journals, and in continental Europe in particular the post-war years have witnessed their revival or their re-emergence in new and sometimes unfamiliar forms. The appearance of a new list is thus most welcome.

The editors claim to include only journals dealing with natural sciences, a term which they have perhaps interpreted rather liberally, for it is hard to understand how, for example, such publications as 'Hunting, Camping and Fishing' of Illinois or *Vins de luxe exotiques* of Paris are allowed to rub shoulders with the academic proceedings of the scientific societies of the world. However, the use of 'World' in the title is amply justified, for the inclusion of say the 'New Guinea Agricultural Gazette' of Rabaul or *Grønlandsposten* of Godthaab, testifies to the immense effort made to procure an exhaustive survey of world scientific literature.

The layout closely follows the lines of the second edition, but although a number of inconsistencies have been removed, several minor irritations persist. The 'World List' should and does serve as a model for bibliographers in the abbreviation of titles of periodicals; it is difficult, however, to appreciate the subtle distinction made between the use of the abbreviation *roy.* for Royal in the 'Proceedings of the Royal Society of Victoria' and that of *R.* in those of the Royal Society of Medicine. The eye is arrested from time to time by disconcertingly large blocks of Russian journals whose titles are quite wisely printed in their original Cyrillic characters, followed in most cases by a transliteration. The alphabetic order, however, in which these publications are listed presupposes a knowledge on the part of the searcher of the 'English' system of Cyrillic transliteration; thus the Ж of Журнал is treated as equivalent to *Zh*, under which the journal will then be found. It would have enhanced the already great value of the book if a recognized international method of transliteration had been followed.

G. N. J. BECK

CHROMATOGRAPHY

Chromatographic Methods of Inorganic Analysis, *by F. H. Pollard and J. F. W. McOmie. Pp. viii* + 192, *with half-tone and line illustrations and colour frontispiece. Butterworths Scientific Publications, London.* 1953. 30*s. net.*

Practical Chromatography, *by R. C. Brimley and F. C. Barrett. Pp.* 128, *with half-tone and line illustrations. Chapman and Hall Limited, London.* 1953. 15*s. net.*

The immense amount of chromatographic work which has now been done throughout the world is reflected in a scattered literature so large as to intimidate the newcomer and to be an unwieldy burden even for experienced workers. There is, therefore, a real need for critical and concise books which reduce the subject to manageable proportions.

It is an indication of the way in which the field has expanded that advanced books now tend to concentrate not upon the whole subject but upon the various subdivisions—such as partition or ion-exchange chromatography—of which the authors have special knowledge. One subdivision which has recently grown very rapidly is that of inorganic chromatography. Although the earliest work in this field may be traced back to Runge, more than a century ago, it is only within the last decade that it has been intensively—and very profitably—explored, and much of the literature is of recent origin. Among the various centres at which inorganic chromatography has been the subject of intensive investigation Bristol is outstanding, and a book from two of the principal workers there is thus particularly welcome. Of 'Chromatographic Methods of Inorganic Analysis' it may be said that it presents clearly and concisely all that one could reasonably expect to find in a volume with this title. Its approach is essentially practical, though there are chapters on such general subjects as the history and the principles of chromatography. Time and again one is made aware of the fact that the authors have encountered difficulties, solved them by simple techniques and devices, and unobtrusively passed on the benefits of their wide laboratory experience to the reader. This book can be warmly recommended to all workers in this field.

'Practical Chromatography' is, as its title indicates, a handbook of laboratory practice. It is, not unnaturally, strongest in the fields in which its authors' main interests lie, and this tends to make it a little unbalanced. Thus treatment of reversed phase chromatography is too brief, even allowing for the novelty of the field. On the other hand, the discussion of gas chromatography draws timely attention to a field which still awaits adequate exploration. Practical requirements are borne constantly in mind, and the reader will find many useful hints on technique and apparatus.

TREVOR I. WILLIAMS

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

BIOCHEMISTRY

Biological Transformations of Starch and Cellulose, *edited by R. T. Williams. Pp.* 84. *Biochemical Society Symposia No.* 11. *Cambridge University Press, London.* 1953. 10*s.* 6*d. net.*

General Biochemistry, *by Joseph S. Fenton and Sofia Simmonds. Pp. xii* + 940. *Chapman and Hall Limited, London.* 1953. 80*s. net.*

BIOLOGY

A Hundred Years of Biology, *by Ben Dawes. Pp.* 429. *Gerald Duckworth and Company Limited, London.* 1953. 30*s. net.*

Kosmos-Lexikon der Naturwissenschaften, A–K. *Pp.* 1591. *Kosmos Gesellschaft der Naturfreunde; Franckh'sche Verlagshandlung, Stuttgart.* 1953. *Half-linen, DM.* 29.50; *half-leather, DM.* 36 *net.*

Le Mécanisme de la Vision des Couleurs, *by J. Ségal. Pp.* 347. *G. Doin et Cie., Paris.* 1953. *Fcs* 3000 *net.*

The Metabolism of Algae, *by G. E. Fogg. Pp.* 149. *Methuen and Company Limited, London.* 1953. 8*s.* 6*d. net.*

Nucleo-Cytoplasmic Relations in Micro-Organisms, *by Boris Ephrussi. Pp. viii* + 127. *Oxford University Press, London.* 1953. 18*s. net.*

Traité de Paléontologie, *Vol. III, edited by Jean Piveteau. Pp.* 1064. *Masson et Cie., Paris.* 1953. *Paper covers, fcs* 9600; *bound, fcs* 10,320 *net.*

BOTANY

Intermediate Botany, *by L. J. F. Brimble.* (*4th edition, revised and rewritten in collaboration with S. Williams and with the assistance of G. Bond.*) *Pp.* 505. *Macmillan and Company Limited, London.* 1953. 20*s. net.*

CHEMISTRY

Analisi Fisico-Chimiche, I, *by G. Buogo* (*2nd ed. revised*). *Pp.* 302. *Sansoni Edizioni Scientifiche, Florence.* 1953. *L.* 2500 *net.*

Chemistry and Man, *four lectures by C. N Hinshelwood, R. P. Linstead, the late J. Drummond, and J. W. Cook. Pp.* 88. *E. and F. Spon Limited; The Chemical Council, London.* 1953. 7*s.* 6*d. net.*

Formaldehyde (*2nd ed.*), *by J. Frederic Walker. Pp.* 575. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 96*s. net.*

The Furans, *by A. P. Dunlop and F. N. Peters. Pp.* 867. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 144*s. net.*

Notions Élémentaires de Chimie Générale à la Lumière des Théories Modernes, *by Paul Pascal. Pp.* 550. *Masson et Cie., Paris.* 1953. *Fcs* 3600 *net.*

Organic Chemistry, *Vols. III and IV, edited by Henry Gilman. Pp.* 580 + *xxxviii and* 665 + *xxxviii. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1953. 70*s. each volume.*

Organic Chemistry, *by P. B. Sarkar and P. C. Rakshit. 7th edition, revised by P. B. Sarkar. Pp.* 598. *H. Chatterjee and Company Limited, Calcutta.* 1953. 8 *rupees net.*

Organic Reactions, *Vol. VII, editor-in-chief Roger Adams. Pp.* 440. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1953. 72*s. net.*

Progress in Organic Chemistry, *Vol.* 2, *edited by J. W. Cook. Pp.* 212. *Butterworth's Scientific Publications, London.* 1953. 42*s. net.*

Structure and Mechanism in Organic Chemistry, *by C. K. Ingold. Pp.* 828. *G. Bell and Sons Limited, London.* 1953. 77*s.* 6*d. net.*

GENERAL

Cybernetics (9th Conference), *edited by H. von Foerster. Pp.* 184. *Josiah Macy Jr Foundation, New York.* 1953. $4 *net.*

Un Demi Siècle de Progrès dans les Travaux Publics et le Bâtiment, 1903–1953. *Pp.* 211 + *cxci. Le Moniteur des Travaux Publics et du Bâtiment, Paris.* 1953. *Fcs* 1400 *net.*

The Hand Produced Book, *by David Diringer. Pp.* 603. *Hutchinson's Scientific and Technical Publications, London.* 1953. 60*s. net.*

Preservazione e Conservazione degli Alimenti, *by Giulio Buogo. Pp.* 221. *Editori-Carlucci, Bari.* 1953. *L.* 1800 *net.*

GEOLOGY

A Manual of Australian Soils, *by C. G. Stephens. Pp.* 48. *Commonwealth Scientific and Industrial Research Organization, Australia. Melbourne.* 1953. 25*s. net.*

Pétrographie des Roches Sédimentaires, *by Albert Carozzi. Pp.* 250. *F. Rouge et Cie., Lausanne.* 1953. *S. fcs* 23.40 *net.*

The Soils of Europe, *by W. L. Kubiëna. Pp.* 317. *Consejo Superior de Investigaciones Científicas, Madrid; Thomas Murby and Company, London.* 1953. 75*s. net.*

HISTORY OF SCIENCE

Chymia—Annual Studies in the History of Chemistry, *Vol.* 4, *edited by Henry M. Leicester. Pp.* 217. *University of Pennsylvania Press, Philadelphia; Geoffrey Cumberlege, London.* 1953. 36*s. net.*

Hallstatt und die Hallstattzeit, *by F. Morton. Pp.* 122. *Verlag des Musealvereines, Hallstatt.* 1953. 25*s.* (*Austrian*).

Justus von Liebig, *by Herta von Dechend. Pp.* 141. *Verlag Chemie, GmbH., Weinheim.* 1953. *DM.* 8.40 *net.*

Un Pionnier de la Physiologie, *by Léon Fredericq. Pp.* 232. *Masson et Cie., Paris.* 1953. *Fcs* 1345 *net.*

PHYSICS

Experimental Nucleonics, *by Ernest Bleuler and George J. Goldsmith. Pp.* 393. *Sir Isaac Pitman and Sons Limited, London.* 1953. 30*s. net.*

History of the Theories of Aether and Electricity—The Modern Theories 1900–1926, *by Sir Edmund Whittaker. Pp.* 319. *Thomas Nelson and Sons, Edinburgh.* 1953. 32*s.* 6*d. net.*

Standard X-ray Diffraction Powder Patterns. *Volume I, by Howard E. Swanson and Eleanor Tatge, pp.* 95; *Volume II, by Howard E. Swanson and Ruth K. Fuyat, pp.* 65. *U.S. Government Printing Office, Washington.* 1953. 45 *cents each volume.*

TECHNOLOGY

Chemical Process Machinery (*2nd ed.*), *by E. Raymond Riezel. Pp.* 735. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 100*s. net.*

Principles of Electronics, *by L. T. Agger. Pp.* 340. *Macmillan and Company Limited, London.* 1953. 18*s. net.*

Reviews of Petroleum Technology 1951. *Pp.* 360 + *viii. Institute of Petroleum, London.* 1953. 50*s. net.*

ZOOLOGY

The Behaviour and Social Life of Honeybees, *by Ronald Ribbands. Pp.* 352. *Bee Research Association Limited, London.* 1953. 21*s. net.*

Clasificación General de los Dípteros, *by Rafael Gonzalez-Rincones and Luisa Guyon. Pp.* 243. *Universidad Central de Venezuela, Caracas.* 1953. *Bs.* 15 *net.*

Gli Animali Commestibili dei Mari d'Italia, *by Arturo Palombi and Mario Santarelli. Pp.* 349. *Ulrico Hoepli, Milan.* 1953. *L.* 3800 *net.*

How Animals Move, *by James Gray. Pp.* 114. *Cambridge University Press, London.* 1953. 16*s. net.*

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Was born in Vienna in 1878 and studied there and at Graz, graduating in 1901. For a year (1902–3) he worked under J. J. Thomson at the Cavendish Laboratory, Cambridge. He returned to Vienna in 1905, becoming successively lecturer in physics, assistant at the *Institut für Radiumforschung* (1920), and professor extraordinary (1927). He was dismissed by the Nazis in 1938 and emigrated to Brussels in 1940. In 1946 he returned to Vienna as head of the II. Physics Institute of the University, retiring, as professor emeritus, in 1951. Is a member of the Austrian Academy of Sciences. Has published numerous papers, principally on gaseous discharge, Brownian movement, and the colour and luminescence of crystals.

W. S. BRISTOWE,
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Was born in 1901 and was educated at Wellington College and Cambridge. He took part in university expeditions to the Arctic and to Brazil, but since he left Cambridge his extensive researches on spiders have been carried out in his spare time. He joined Brunner Mond in 1925, travelled extensively in Asia, and is now head of the central staff department of Imperial Chemical Industries Limited. Although he has written several monographs on taxonomy his principal researches have been in the field of biology, and his main published work has been 'The Comity of Spiders' (Ray Society, Vol. I, 1939; Vol. II, 1941).

Made and printed in Great Britain at THE KYNOCH PRESS, *Witton, Birmingham, 6, for the publishers,*
IMPERIAL CHEMICAL INDUSTRIES LIMITED, *London, S.W.1*